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TRANSACTIONS OF 1940

PART I
REPORTS AND PAPERS
JOINT REGIONAL MEETING
SECTION OF HYDROLOGY
AND
WESTERN INTERSTATE SNOW-SURVEY CONFERENCE

SOUTH PACIFIC COAST AREA
STANFORD UNIVERSITY, CALIFORNIA,
JANUARY 12-13, 1940

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[Parts III and IV, to contain reports and papers at joint regional meetings of Section of Hydrology and American Association for the Advancement of Science, are in preparation]

PREFACE

The American Geophysical Union was established in 1919 as the American Committee of the International Union of Geodesy and Geophysics, and its Executive Committee is the Committee on Geophysics of the National Research Council. The objects of the Union are to promote the study of problems concerned with the figure and physics of the Earth, to initiate and coordinate researches which depend upon international and national cooperation, and to provide for their scientific discussion and publication. In the accomplishment of these objects, the Union is divided into Sections following the plan of organization of the International Union of Geodesy and Geophysics. There are now eight sections, namely, (a) Geodesy, (b) Seismology, (c) Meteorology, (d) Terrestrial Magnetism and Electricity, (e) Oceanography, (f) Volcanology, (g) Hydrology, and (h) Tectonophysics. A Section of Geophysical Chemistry was discontinued May 31, 1924, as the International Union had failed to provide such a Section. The Section of Hydrology was established November 15, 1930--matters pertaining to scientific hydrology referred to the American Geophysical Union had been previously looked after by special committees on Hydrology. The Section of Tectonophysics was established April 9, 1940, for the purpose of promoting and encouraging research of fundamental importance to our knowledge of Earth-structure not covered in any one of the other Sections of the Union.

General assemblies of the Union and meetings of its Sections for presentation and discussion of papers and symposia are held in Washington, D. C., each year. The first annual meetings were those of 1920. Following the formation of the Section of Hydrology, Regional Meetings have been held usually in joint sessions with other organizations having coordinated interests. For the purpose of such meetings, the Executive Committee of the Section of Hydrology designated selected Regional Areas and their territories, namely: North Continental Divide--Montana, Idaho, eastern Washington, Oregon, and Alberta (affiliated); South Continental Divide--Colorado, Wyoming, Utah, and New Mexico; North Pacific Coast--western Washington, Oregon, Alaska, and British Columbia (affiliated); South Pacific Coast--California, Nevada, Arizona, and Hawaii.

Thus far, Regional Meetings have been held as follows [references to publication of proceedings given refer to the "Transactions" of the American Geophysical Union, Part, and year]: South Pacific Coast Area at Berkeley, California, June 20 to 21, 1934, jointly with Western Interstate Snow-Survey Conference, June 21, 1934 [Part II, 1934, pp. 522-611 and pp. 612-633]; South Pacific Coast Area at Pasadena, California, January 31 to February 1, 1936, jointly with Western Interstate Snow-Survey Conference, January 31, 1936 [Part II, 1936, pp. 455-528 and 529-562]; South Continental Divide Area at Denver, Colorado, June 21 to 26, 1937, jointly with South Continental Divide Snow-Survey Conference, June 25-26, 1937 [Part II, 1937, pp. 509-600 and pp. 601-663, with addendum Part II, 1938, pp. 668-669], and with Society of American Foresters, June 22, 1937 [Journal of Forestry, v. 35, 1937, pp. 991-1055]; North Continental Divide Area at Spokane, Washington, December 28 to 29, 1937 [Part II, 1938, pp. 590-594]; South Pacific Coast Area at Davis, California, January 8 to 9, 1938, jointly with Western Interstate Snow-Survey Conference, January 8, 1938 [Part II, 1938, pp. 597-667 and pp. 671-744]; South Pacific Coast Area at Los Angeles, California, December 16 to 17, 1938, jointly with the Western Interstate Snow-Survey Conference [Part I, 1939, pp. 1-52 and pp. 53-96]; North Continental Divide Area at Spokane, Washington, December 28, 1938, jointly with the Western Interstate Snow-Survey Conference [Part I, 1939, pp. 97-124 and pp. 125-140].

Parts I-A and I-B of the present volume, "Transactions of 1940," contain the papers, symposia, and discussions at the Regional Meeting held for the South Pacific Coast Area at Stanford University, California, January 12 to 13, 1940, jointly with the Western Interstate Snow-Survey Conference, January 12, 1940.

The officers of the Section of Hydrology, and the officers and members of the Regional Committees responsible for the meeting at Stanford University and of the Executive Committee of the Western Interstate Snow-Survey Conference, are as follows:

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The costs of publication for the transactions of the Regional Meetings of the Section of Hydrology were provided by the American Geophysical Union. Those for the proceedings of the Snow-Survey Conferences were contributed by interested organizations and individuals and by the American Geophysical Union. Assembly and preliminary editing of the manuscripts were made by the chairmen of the several committees concerned, by Dean Samuel B. Morris, and by Dr. J. E. Church. Final editing, preparing of master-copy, and publishing were done by Dr. J. A. Fleming and J. J. Capello, General Secretary and Assistant Secretary, respectively, of the American Geophysical Union. For the necessary redrawing of figures and photographic work for publication, we are indebted to W. C. Hendrix and P. G. Ledig.

The success of the Stanford University joint Regional Meeting of the Section of Hydrology and the Western Interstate Snow-Survey Conference furnishes another example of the enthusiasm and efforts of our Western colleagues in the economic and scientific aspects of both hydrology and snow-surveying.

J. A. Fleming, General Secretary,
American Geophysical Union

AMERICAN GEOPHYSICAL UNION
REGIONAL MEETING
SOUTH PACIFIC COAST AREA
January 12-13, 1940

PART I-A

SECTION OF HYDROLOGY
REPORTS AND PAPERS

Stanford University, California

January 12, 13, 1940

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JOINT REGIONAL MEETING AT STANFORD UNIVERSITY, CALIFORNIA

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THE PROBABILITY-VIEWPOINT IN HYDROLOGY

Eugene L. Grant

Perhaps the first reaction to the title of this paper may be "Why discuss probability? If that approach in hydrology has not already been discarded, it ought to be." Certainly the critical attitude toward studies of probability expressed in much recent engineering literature would suggest this conclusion. The following quotation from an article "Possible and probable future floods" by William P. Creager in the November, 1939, issue of Civil Engineering is representative:

"About 1914 the theory of probabilities was applied to flood studies; that is, curves were derived indicating by past records on a stream the frequency with which, during a long period, a given flood should be expected. Notwithstanding the fact that periods of record sometimes did not exceed 20 years and very seldom exceeded 30 or 40 years, these probability-curves were extrapolated to estimate the flood which would be expected during long periods--once in 1,000, 5,000, 10,000 years, etc. Then, according to the judgment of the engineer, the 1,000-, 5,000-, or 10,000-year flood was selected for the design-capacity of the spillway.

"So seriously was this method of estimating floods taken that numerous articles appeared in the technical publications defining more exact methods for such extrapolation by the use of Pearson's and other functions; the writer included chapters on the method in two books; other books dealt with them; and the late Allen Hazen devoted an entire volume to the subject.

"Recently, however, it has been proved by advanced studies and a greater accumulation of data that the probability-method is entirely inadequate. Data on floods of many years ago and gagings of more recent floods have shown conclusively that there must be a combination of meteorological conditions which give rise to storms of a special class, which occur so infrequently that their resulting floods seldom appear on the published records of a given river. These storms and their resulting floods seem to be in a different class from ordinary ones and to follow some law of their own.

"Thus floods have occurred on rivers which, based upon probability-studies of prior records of considerable length, would have a frequency, not of the usually adopted 1,000 to 10,000 years, but of once in millions and even billions of years."

The December, 1939, issue of Civil Engineering contains as an editorial a letter written by the late Thaddeus Merriman. Among other matters, this letter comments in a vein somewhat similar to that of Mr. Creager's article. The phrase "thousand-year flood" is described in slighting terms as a "catch-phrase" that has survived because of its catchiness. "Engineering when applied to dams is not the art of producing the most dam for the least money but the safest dam irrespective of cost," said Mr. Merriman. The engineer's duty "demands absolutely that the public be afforded a maximum of safety. If the client is unwilling or unable to pay for that maximum, then he should not have that dam."

When these and other similar critical comments are examined in detail, they seem to imply two different objections to the application of the probability-approach in hydrology to practical problems of engineering design, as follows:

(1) The probability-approach is unsatisfactory because it is not practicable to make a reliable estimate of the value of the variable--that is, flood discharge, rainfall, and annual runoff--associated with the desired probabilities.

(2) The probability-approach is unsatisfactory because the hydraulic engineer should be concerned with the most unfavorable possible combination of conditions rather than with the respective probabilities of the various extreme conditions.

I have no quarrel with these criticisms provided they are limited to the situations to which they properly apply. However, it would be unfortunate if their repetition without qualification in engineering literature should lead anyone to believe that the probability- or frequency-viewpoint in dealing with problems of hydrology should be discredited. The purpose of this paper is to point out that this viewpoint is frequently necessary for the design of hydraulic structures for maximum economy, and to indicate some limitations on its practical application.

Although the first criticism applies legitimately to the various methods of extrapolation which have been used for estimating such extreme floods as the so-called thousand-year flood, there are many probability- or frequency-estimates of rainfall or runoff to which it does not apply. The second criticism applies to only a very small proportion of the total number of hydraulic structures that are built--those in which a failure would be a catastrophe involving probable loss of human life; for the economic design of most hydraulic structures, it is desirable for the designer to know the respective probabilities of various conditions short of the most unfavorable one.

Let us start our examination of the first criticism by examining the meanings of the word "probability."

The word probability is understandable enough when used qualitatively in everyday speech. If I say it will probably rain tomorrow, you know what I mean, whether or not you agree with me. But if I say the probability of getting a hand in bridge with no card higher than a nine-spot is 1 in 1,830, that statement requires further explanation. So also does a statement that the probability is 0.18 of getting at least one rainfall per year of 1.75 inches or more in a 60-minute period at Chicago, Illinois. In fact, these two quantitative statements require not only further explanation but different sorts of explanation.

The probability for the hand in bridge may be obtained by comparing the 347,373,600 different hands with no card above a nine-spot with the 635,013,560,000 different possible 13-card hands from a 52-card deck. This involves the use of the classical or combinatorial definition of probability. If an event may happen in a ways and fail in b ways, and all of these ways are equally likely to occur, the probability of the event happening is $[a/(a + b)]$, the ratio of the number of ways favorable to the event to the total number of ways.

Obviously this definition cannot be used to interpret the meaning of the statement regarding the rainfall at Chicago. It is not possible to enumerate a number of equally likely ways in which it can rain 1.75 inches in an hour, or fail to do so. A quite different idea thus appears--that of frequency. This idea implies a definition of probability that may be stated somewhat as follows: Assume that if a large number of trials of an event are made under the same essential conditions, the ratio of the number of trials in which a certain event happens to the total number of trials made will approach a limit as the latter number is increased indefinitely; then the limit thus described is defined as the probability that the event shall happen under these circumstances [see 1 of "References" at end of paper].

These two concepts of probability are closely related in somewhat the same way that the ideal concepts of geometry are related to actual physical bodies. In both we are dealing with a ratio whose numerical value lies within the range zero to unity, zero corresponding to an impossible occurrence and unity corresponding to an occurrence which is certain to happen. In many instances it is possible to demonstrate that observed frequencies check with those which are anticipated by the classical or combinatorial approach.

Obviously records of relative frequency in the long run must be the source of any estimates of probability made in hydrology. (Indeed, some notable contributions to hydrology which have used this point of view have employed the word "frequency" throughout without any mention of "probability.") However, it is often advantageous to apply mathematical theorems developed from the classical definition to probabilities obtained from observations of frequency.

For instance, it is illuminating to ask the question "Suppose 100 trials were made of an event with a constant probability of occurrence of 0.01, what would be the respective probabilities that the event would not occur at all, that it would occur exactly once, that it would occur exactly twice, and so on?" Theory of probability tells us that this may be answered by evaluating the successive terms of the binomial $(0.99 + 0.01)^{100}$. Thus if there is such a thing as a one-percent-chance flood (sometimes loosely called a 100-year flood) on a given stream, the probability is $(0.99)^{100} = 0.366$ that a flood of this magnitude will not occur at all during any given 100-year interval, 0.370 that it will occur exactly once, 0.185 that it will occur exactly twice, and 0.079 that it will occur three or more times. Such calculations shed some light on the difficulties of estimating the one-percent-chance flood from even a 100-year record. Not to mention the difficulties of estimating it from a 30-year record!

I agree with the critics of the probability-approach in hydrology that there is no reasonable basis for estimating the magnitude of such an extreme flood as the 0.1-percent-chance flood (so-called 1,000-year flood) by any method of extrapolation from a 20- to 40-year record. There is no justification for the choice of some one particular mathematical function which is to be assumed to connect the observed flood-values in a short period of record with the magnitude of the flood that in the long run would be expected one year in 1,000. A number of quite different mathematical frequency-functions may seem to fit an observed small sample equally well and yet have widely different implications when extrapolated. As might be anticipated, different investigators using extrapolation methods in the study of flood-frequencies have in fact obtained very different results; the flood that one man expects one year in 500 years will be considered by another using the same data as likely to occur one year in 57 [2].

The objective of any study in meteorology or hydrology that aims to determine the magnitude of rainfall or runoff associated with certain desired probabilities should be to reach this result by interpolation rather than extrapolation. Often the desired probabilities are so small that this ideal may not be realized with the limited period of record available. Where this is true the results obtained should be viewed with a skepticism that increases with the degree of extrapolation.

Sometimes, however, it is possible to find ways of combining records that permit interpolation in cases where at first glance extrapolation appears necessary. In a recent study [3] of the frequency of very intense rainfalls of short duration this was done successfully by the combination of records of 33 years' duration from each of ten stations scattered throughout middle western United States to give the equivalent of 330 years of record.

Whenever such a combination of records is made the assumptions implied by the combination should be recognized and checked to see if they seem reasonable under the circumstances. One assumption in this rainfall-intensity study was that the records at the different stations were independent--in other words, that the same intense storms were not being counted at two or more stations. This assumption was obviously correct in this instance as the stations were scattered over eight States whereas records in a locality which had a number of rainfall-stations closely spaced proved that these high-intensity storms extend over only a few miles. Lacking such evidence, the independence of the records at any two stations might have been confirmed statistically by finding that the prediction of a given year's storm-magnitude or storm-frequency at one station could not be improved by knowing the same year's storm-magnitude or frequency at the other station--in other words, that the correlation-coefficient between the results at the two stations was not significantly different from zero.

Another assumption in combining records from different stations is that the data are statistically homogeneous, that is, that the same constant system of chance causes is operating at each station. In the rainfall-intensity study cited this involved combining records from stations that differed considerably in general climate. Here a statistical study of the storm-records themselves formed the basis for concluding that, despite other climatic differences between the stations, they were similar with respect to the chance of high-intensity rainfalls of short duration. (It is interesting to note that, although high-intensity storms of short duration such as are important in the economic design of storm-sewers appeared to be subject to the same system of chance causes throughout a large area of middle western United States, this was not true of the lower brackets of "excessive rainfall" as it is defined by the United States Weather Bureau.) Modern statistical methods, such as the chi-squared test of goodness of fit, provide various tests for homogeneity that may be applied to such a problem.

The frequency-definition of probability assumed successive trials made "under the same essential conditions"; that is what is implied in Shewhart's [4] phrase "a constant system of chance causes." Whenever past rainfall- or runoff-records are assumed to be a random sample subject to the same system of causes which is expected to operate in the future, the question may arise whether this assumption is correct. It may not be correct if we have (1) activities of man making substantial changes in conditions affecting rainfall and runoff, (2) perceptible long-term upward or downward trends due to natural causes, or (3) climatic cycles.

Some activities of man may obviously change the system of causes operating; for instance, a storage-reservoir necessarily affects flood-discharges below it. In other cases changes may be observed but it may be uncertain whether or not they have much influence on the climatic variable under consideration. Consider, for example, the controversial question of whether rainfall is changed when forest-cover is partly removed. Here any judgments should be based on statistical studies of rainfall before and after conditions have changed. The improved techniques of statistical inference developed within the past 15 years or so by R. A. Fisher, Harold Hotelling, Walter Shewhart, and others should be helpful in dealing with troublesome problems of this type.

Although climatic trends exist over periods of geologic time, their operation is evidently so slow that they may be neglected in any rainfall- and runoff-studies which it is now practicable to make.

Judging the influence of climatic cycles involves greater difficulty. In considering the concentration of wet and dry years which we observe in examining past records of rainfall, runoff, lake-levels, and tree-ring growth, one question which we may ask is whether "cycle" is an appropriate name for them. (The dictionary definition of a cycle is "an interval or space of time in which is completed one round of events or phenomena that recur regularly and in the same sequence.") Certainly past rainfall-series, for instance, contain no combination of harmonics that may be used for forecasting in the way in which the elements of tidal variation are used to forecast the tides. It would be an interesting subject for a statistical study to examine a large number of rainfall-series to determine whether the observed concentrations of wet and dry years are consistent with the hypothesis that they are merely chance concentrations such as would be expected in random sampling without any change in the system of chance causes operating. Certainly similar apparent "cycles" are observable in series which are known to be made up by random sampling [5]. Shewhart has developed criteria for the determination of departures from a constant system of chance causes; my own application of some of his criteria to a few rainfall- and flood-series has failed to exhibit the evidence of departure from such a cause system which would be expected if a cycle were present.

A sound view of the present status of this controversial cycle-question was expressed by John C. Hoyt [6] as follows: "Until a cause is established, it will not be possible to predict rainfall even for one year in advance. This places the science of water-supply estimates on a purely empirical basis. Under present knowledge, engineers may view the recurrence of droughts as somewhat similar to the drawing of cards from a deck. An exceptionally dry year may occur with somewhat the same frequency as an exceptionally bad hand in bridge, but an estimate of the average period of recurrence can be based only on observations and not on mathematical probabilities. No definite law of recurrence has been established. Studies of tree-rings have been carried back for centuries in some regions without definitely revealing a repeating cycle."

Near the start of this paper it was stated that those cases in which design ought to be for the most extreme condition conceivable were the exception rather than the rule in hydraulic design, and that economic design usually implied the probability- or frequency-viewpoint. How may this viewpoint be used in practical design problems? In what way may an association of a definite probability or frequency with a given extreme condition of runoff help in the design of an hydraulic structure or project for greatest economy?

Consider, for example, the problem of economic design of a system of storm-sewers. The provision of sewer-capacities sufficient to carry the maximum storm that might conceivably occur under the most unfavorable circumstances would be likely to involve a prohibitively high first cost of the sewers. Even though this cost were not prohibitive, it probably would be uneconomical to provide such capacities; it would be better to occasionally suffer the damages that occur when the sewer-capacity is exceeded than to make sufficient investment to prevent the damages.

To get this problem out of the "hunch" stage and into the stage of measurement of the values involved, it is necessary to make a series of alternative designs with various frequencies with which the sewer-capacities are expected to be exceeded, and to estimate the first cost for each design. Each first cost should be converted into equivalent annual cost over the prospective life (by multiplying by a capital-recovery factor which takes account of both interest and depreciation) and the estimated annual cost of operation and maintenance added to this. The damages from a storm which exceeds sewer-capacities should be estimated in terms of money as nearly as practicable; from the estimated frequency with which these damages would be expected to occur with each design, the average annual damages may be estimated for each. The design which gives the lowest total for sewer-costs plus damage-costs is the one which appears most economical. As in all engineering studies of economy, the comparison should be considered as only one of the guides to the final choice which should also give weight to any prospective differences between the alternatives not reduced to terms of money, for example, difficulties of financing, uncertainties in estimates, effect on real-estate values.

Although the difficulty of reducing estimates of damages to terms of money is an obstacle to the use of this method with a high degree of precision, it can nevertheless be a valuable guide to judgment. An advantage of this approach is that once an "ideal" frequency of overflow is determined, the design of the entire system may be made consistent with that frequency. If the probability of various storm-runoffs for each sewer are estimated, this avoids having an uneconomical excess capacity in one part of the system which is not used because of deficiency of capacity in another part. For instance, Chicago's combined sewers are now designed, wherever practicable, on the basis of a frequency of overflow of once in five years; this is an ultimate objective for the entire system even though the capacities of many of the older sewers are such that they will overflow more frequently.

In some other hydraulic structures in which the damages from an extreme discharge exceeding the designed capacity are high in proportion to the cost of providing excess capacity, economic design requires consideration of the flow associated with very small probabilities. If these small probabilities are associated with events so unlikely that they may not happen during the life of the structures, the problem is one of finding which of several alternative designs gives the most favorable gamble.

To explain this statement, consider first an imaginary situation which is artificially simple and which has no relation to hydrology. Suppose the Government should embark on an annual capital levy to which anyone with a specified amount of property might be subject; by drawing lots a $5,000 assessment would be made against one out of every 400 eligible to be taxed in this manner. How much could an individual afford to pay to be relieved of this risk?

If some of the individuals subject to this hazard should join together into a mutual insurance company to eliminate the hazard of severe loss to any one member of the group, and each should pay into a common pool $12.50 (that is, 1/400 of $5,000) each year, this would, in the long run, be enough to meet the losses incurred by the unfortunate ones whom the drawing of lots designated as subject to the capital levy. Of course, if such a mutual insurance company actually were formed it would have expenses of selling, administration, and collection, and its charges to its members would have to be sufficient to provide the necessary payments in those years in which its members' losses were greater than average; thus its annual premium would doubtless be considerably more than $12.50. Nevertheless the figure of $12.50 might be thought of as the bare "cost of the risk"; in gambling parlance, the individual who paid it would be getting a fair bet.

In this sense the cost of risk of some undesired event is the product of the probability of its occurrence and the expected loss if it does occur. An application of this viewpoint to the problem of determining maximum economy in spillway-design was suggested by the late Allen Hazen [7]. The following illustrative problem is adapted with modifications from a case which he described:

A large public-utility company acquired a recently constructed small hydroelectric plant in connection with the purchase of a small utility-property. It seemed to the engineers of the large company that the spillway-capacity of 1,700 cubic feet per second provided by the dam at the plant was inadequate; it was believed that a flood exceeding this capacity would cut through an old river-channel and by-pass the plant. A rough estimate of the cost of the necessary reconstruction should this occur was $200,000.

In order to determine what, if any, increase in spillway-capacity was justified, the engineers estimated the costs of increasing the spillway-capacity by various amounts and the probabilities of floods of various magnitudes. Annual investment charges on the spillway-enlargement were assumed as eight per cent (interest at six per cent, sinking-fund depreciation based on a 50-year life at 0.35 per cent; taxes at 1.65 per cent). The annual "cost of the risk" was calculated as the product of the expected damage of $200,000 if spillway-capacity were exceeded and the probability of its occurrence; this might be thought of as a fair charge for flood-insurance if such insurance were available. The relation of annual costs to spillway-capacity is shown in Table 1.

Table 1--Annual costs for different spillway-capacities

Spillway-capacity	Probability of greater flood in any one year	Cost of enlarging spillway-capacity to provide for this flood	Annual investment charges at 8 per cent	Annual "Cost of flood risk"	Sum of annual costs
cfs					
1700	0.05	No cost	$ 0	$10,000	$10,000
2000	0.02	$30,000	2,400	4,000	6,400
2300	0.01	46,000	3,680	2,000	5,680
2700	0.005	62,000	4,960	1,000	5,960
3100	0.002	81,000	6,480	400	6,880
3400	0.001	104,000	8,320	200	8,520

These calculations appear to indicate that it would pay to enlarge the spillway to provide at least against the flood which may be expected one year out of every 100 years. If other matters not considered in the financial calculations should favor a greater spillway-capacity, such a tabulation provides a measure of the costs of each increment of capacity as an aid to judgment.

As already indicated, one practical difficulty in the way of making such calculations is the great uncertainty involved in estimating floods of small probability where this is done by extrapolating frequency-curves.

In general, the conclusion of this paper is that estimates of the expected frequencies of various extreme conditions should be recognized as a desired objective in most hydrologic studies, even though it is not always practicable to realize this objective. Wherever possible, investigators should endeavor to develop methods of analysis which permit estimating these frequencies by interpolation rather than by extrapolation.

References

[1] This discussion of probability-definitions is adapted from that in "Theory of probability as applied to telephone problems" by Paul P. Coggins and Roger I. Wilkinson.

[2] See discussion by C. S. Jarvis, Proc. Amer. Soc. Civil Eng., Papers and discussions, p. 2028, Oct. 1927.

[3] A. J. Schafmayer and B. E. Grant, Trans. Amer. Soc. Civil Eng., v. 103, pp. 344-401, 1938.

[4] Walter Shewhart, Economic control of quality of manufactured product, D. Van Nostrand Co., New York, 1931.

[5] In Table A, pp. 442-445, and Table D, pp. 454-463, of "Economic control of quality of manufactured product," Shewhart gives the result of 4,000 successive samples from a normal universe; this may be compared with a series of annual rainfalls. In "A random-difference series for use in the analysis of time series," J. Amer. Statis. Assn., v. 29, p. 11, 1934, Holbrook Working gives a long series from a cumulation of random changes; this is comparable to a lake-level series.

[6] National aspects of the drought, Civil Eng., v. 1, p. 1167, 1931.

[7] Allen Hazen, Flood flows, John Wiley and Sons, 1930.

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DISCUSSION

L. S. HALL (Hydraulic Engineer)--The writer has followed since 1918 the developments of the use of probability-methods in hydrologic studies and has come to the conclusion that there are certain types of data, particularly maximum flood-flow intensities, for which it is impossible to expand a short record covering a period of 10 to 30 years by any mathematical method so as to reach even an approximately accurate figure for the probable maximum occurrence in a longer period of time, such as 100 years. This is due to the extreme skewness of this type of data. As a result, a record of considerable length must be available before the maximum occurrence can be known with any degree of certainty. In other words, it is very likely that we shall require a record of at least 200 years on many streams in order to prophesy, with any degree of accuracy, the probable maximum occurrence during a 100-year period.

The mathematical treatment used by actuaries in determining probabilities are predicated on the use of several thousand terms. A long record of actual experience is a prerequisite to an accurate mathematical treatment. The combination of the short-term records of a single type of data from several stations of similar characteristics is helpful; but such a record, regardless of the ingenuity used in combining the various short elements, is not equal to a single long-term record at one station. Other methods of approach, such as transposition of storms in the case of flood-runoff studies, must be used until longer records are available.

For certain types of data, where the probable occurrence in the shorter period of time such as 10 years is desired, a record of 20 to 30 years' duration can be used with some assurance. Such a use is the determination of the probable cycles of two, three, four, or more dry years in succession, which would cause a serious draft on storage-reservoirs that depend on cyclic storage. If the stream-flow records are divided into the probable percentage of time in which the flow will be greater or less than a given quantity, the probable occurrence of combinations of years can be determined by expansion of the equation by the binomial theorem. For example, if it is determined that a runoff less than a given amount will occur on the average once in 10 years, then the occurrence of two successive years of this amount will occur with frequency equal to the square of 1/10, or once in 100 years. Similarly, the occurrence of three, four, five, and six successive dry years in a 100-year period will occur at the percentages of time equal to 22, 32, 40, and 46 per cent, respectively, on the probability time-scale.

This application of the principle of probability is of considerable value in water-studies on large storage reservoirs.

HYDROLOGY OF THE SANTA CLARA VALLEY, CALIFORNIA

Edward Hyatt

Note--The report of the investigation was completed in 1933 and was published as Bulletin 42 of the Division of Water Resources, Department of Public Works, State of California, under the title "Santa Clara investigation." The paper was abstracted from that report and the conclusions presented are those of the Bulletin, although they have been supplemented slightly by information collected later.

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DESCRIPTION AND RESULTS OF OPERATION OF THE SANTA CLARA VALLEY WATER CONSERVATION DISTRICT'S PROJECT

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The Santa Clara Valley Water Conservation District, comprising the major part of the Santa Clara Valley, was formed for the purpose of harvesting the waste flood-waters of the surrounding watersheds and of charging these waters into the porous strata beneath the Valley which form the underground reservoir from which the Valley's irrigation and domestic waters are drawn, and which was in an advanced stage of depletion. This situation was brought about by the growth of the fruit and vegetable-raising industry with its resultant increasing use of irrigation-water until the yearly draft upon the underground reservoir exceeded the yearly replenishment and a continued decline of water-levels occurred. Several investigations of the water-resources of the Valley were made and culminated in the formation of the District, the construction of storage-dams and of percolating works, the collection and conveyance by these works of waste-water to the underground reservoir, and the consequent rising of the Valley's water-levels.

The Santa Clara Valley is located southerly from the Bay of San Francisco. The Coast Range mountains on the west and the Mt. Hamilton range on the east approach each other at a point about 20 miles south of the southern end of San Francisco Bay and enclose the principal valley in a bowl-shaped and nearly circular area with greatest general dimensions north and south 20 miles, and east and west 13 miles. At the south side the encircling mountains are broken by a pass known as the Lower Gorge of the Coyote, which opens into an extension of the main valley reaching as far south as Madrone, with a length of eight miles and greatest width of four miles. This extension is known locally as the Coyote Valley. The total length of the combined valleys from the County line at Palo Alto to Madrone is 36 miles. Within this area is included the major portion of the valley-lands of Santa Clara County.

Many streams enter the Valley from the surrounding mountains. Principal among these are the Coyote on the south and Alamitos, Guadalupe, Los Gatos, Campbell, and Stevens Creeks on the west.

Numerous towns and cities are scattered over the area. The principal city, situated in the geographical center of the main valley, is San José, with a population of about 80,000. Quite uniformly distributed from north to south are the smaller cities and towns of Mountain View, Santa Clara, Los Gatos, Saratoga, and Campbell.

The topography of the Valley is that of a bowl-shaped amphitheater, with an open side to the north facing San Francisco Bay. At one time the waters of the sea probably covered the entire valley, forming an enlarged bay, with the outlet to the south through the Lower Gorge and Coyote Valley.

With the subsidence of the sea, or elevation of the land, the gradual erosion of the surrounding mountains filled the valley-floor to great depths with the gravels, sands, and clays. This process has resulted in sloping the plains from the west, south, and east toward the north center at present sea-level. The slopes are quite steep next to the hills, gradually flattening as sea-level is approached, with broad flat ridges or "cones" of greater or less local prominence created by the various streams as they have swung back and forth over the valley-floor during flood- and deposition-periods. This building up by deposition of water-borne materials has resulted in a most irregular arrangement of the gravels, sands, and clays comprising the valley-floor, but in general the materials shade from coarse gravels at the foothill margins to the fine sands and clays of the sea-level. The local topograpny of the valley-floor is wholly influenced by this building effect of the local streams, this in turn affecting the soil types and the resulting crops.

Elevations for the valley-floor range from sea-level on the north to an average of about 200 feet above sea-level on the east and south and 300 feet on the west at the general line of the toe of the foothill slopes. A few small areas that might be classified as a part of the valley-floor proper reach an elevation of 400 feet. The surrounding mountains have a maximum height on the west of 3,800 feet with an average height along the crest line of 2,400 feet, whereas on the east a maximum elevation of 4,400 feet is reached at Mt. Hamilton.

The Coast Range (or Santa Cruz) mountains on the west are for the most part heavily timbered and brush-covered, coniferous trees largely prevailing. In the easterly (or Mt. Hamilton) range the mountains are more open, with grass and brush-cover and some secondary timber, mostly oak.

Climatically the Valley is highly favored. The surrounding mountains protect it from the frequency and sweep of the western winds which prevail farther north in their passage through the Golden Gate and across the Northern Bay and hills into the great interior valleys. The Coast Range which acts as a barrier and deflector for these oceanic winds also holds back the coastal fogs. In the same manner that the Valley is protected on the west from the winds and fog of the ocean it is also protected on the east by the Mt. Hamilton Range, which acts as a barrier to the excessive summer heat of the interior valleys. While guarded in its summer climate by the agencies cited from the extremes of either prolonged valley-heat or coastal rawness, there is a moderate but not prolonged summer heat, tempered in the main Valley by proximity to the open Bay on the north.

Thus placed between the ocean and the great interior valley of the San Joaquin, but protected from the extremes of heat or cold of either, and with the tempering effect of proximity to salt water in the sheltered portion of San Francisco Bay, the climate is moderate in all its extremes, conducive to pleasant living and work, ideal for residence, and one particularly favorable to the deciduous crops produced.

Fruit-growing, and its attendant packing industry are the major industries of the Valley. The total cultivated acreage within the District is now 107,000 acres, of which about 60,000 acres are in deciduous fruits, principally prunes. Orchard-planting began in the early "eighties" and increased steadily to 1913 when there were 33,000 acres bearing. There was a lull between 1913 and 1918, but the acreage has gained steadily since then until the present.

Prior to 1898 very little of the land was irrigated. The sentiment of what few orchardists there were then was against irrigation and the rest of the land was dry-farmed. However, the next two years, 1898 and 1899, were deficient in rainfall and opinion began to change in favor of irrigation for orchards. At first most of the irrigating was done by growers adjacent to streams with water diverted from the streams during winter and spring when water was available, but another dry year in 1908 resulted in a turn to the more dependable underground water-supply and the practice of pumping from wells became firmly established. This practice spread rapidly. In 1912, 29 per cent of the Valley's lands were irrigated and in 1920, 67 per cent were irrigated, including 90 per cent of the orchards, and nearly all with water pumped from wells. The period 1920 to 1934 was abnormally dry. More and more wells were drilled and the irrigated acreage increased rapidly, until in 1934 practically all the irrigable land was under irrigation.

By 1912 the pumping draft was heavy enough to cause a decline in water-levels whenever the yearly rainfall was less than normal. Although the levels rose during the wet years of 1915 and 1916, from then on they fell steadily until 1934. In 1920 the water was 30 feet lower than in 1913, causing the formation of the "Santa Clara Valley Water Conservation Committee" who engaged Fred. H. Tibbetts and Stephen E. Kieffer, civil engineers of San Francisco, to investigate the water-resources of the Valley.

The investigation made was very comprehensive and detailed. It involved the regular measurement of about 600 wells to determine water-level fluctuations; it determined the position, extent, origin, and movement of underground water; covered the economic study of the development of the Valley, growth of the demand for water, and probable rate and final extent of the Valley's development and water-demand; it included a complete analytical study of rainfall and runoff of the surrounding watersheds and the portion of the runoff that could be conserved and used to replenish the underground supply; and it proposed methods and works for such conservation and use.

According to the Tibbetts and Kieffer report, as well as to an earlier report entitled "Ground-water in Santa Clara Valley, California" by W. O. Clark and published as United States Geological Survey Water-Supply Paper 519, the underground reservoir is practically entirely supplied by rainfall on the surrounding mountains which runs off in the streams and which percolates underground from those parts of the stream-beds near the rim of the Valley where the water-bearing strata are connected with surface stream-beds.

The underground reservoir is not one body but is composed of numerous interlaced channels of porous alluvial material which slope from ground-surface at the Valley's edge to considerable depth beneath a clay layer near the bay. The channels are practically continuous where the streams enter the Valley but fan out and vary greatly in depth in the wider valley. The available porosity of the valley alluvium was calculated by Tibbetts and Kieffer as 11.1 per cent and by Clark (Water-Supply Paper 519) as about 12 per cent, both figures being based on well-logs.

From a study of the 18-year period between 1902 and 1920, which was practically a normal period as to rainfall, Tibbetts and Kieffer estimated maximum, minimum, and average yearly rainfall, runoff, and percolation for the Valley. Normal annual rainfall on the watershed of 450 square miles was estimated as 27 inches. The estimated annual runoff is 202,500 acre-feet average--458,200 acre-feet maximum and 19,300 acre-feet minimum. About 82 per cent of the runoff usually occurs in January, February, and March.

The estimated annual percolation is based on absorption-measurements by Tibbetts and Kieffer on several streams for different volumes of flow and on measurement of absorption on the Coyote River by the Bay Cities Water Company for seven of the years between 1902 and 1918. These indicated an annual percolation of 125,800 acre-feet maximum, 18,200 acre-feet minimum, and 76,500 acre-feet average.

Runoff wasted to the bay was estimated to be 319,400 acre-feet maximum, 1,100 acre-feet minimum, and 126,000 acre-feet average. The average waste was about 56 per cent of the total runoff. It was also estimated that during years of maximum runoff about 13,000 acre-feet were diverted for irrigation, principally from Los Gatos Creek.

In 1920 the irrigated area was 74,400 acres and the yearly pumping draft was 67,700 acre-feet. Tibbetts and Kieffer estimated that the ultimate irrigated area would be 107,000 acres, and that the ultimate normal pumping draft to irrigate this acreage and to supply domestic water for the cities of the Valley would be about 159,000 acre-feet and would occur about 1930.

The investigators concluded that, although draft had not at that time exceeded normal natural replenishment and although the observed water-table declines were in the nature of fluctuations rather than a permanent trend, a yearly average deficiency of about 82,000 acre-feet would occur by the time the Valley was fully developed and the water-level would then decline progressively unless means were taken to replenish the supply.

In 1930 to 1933 the State Division of Water Resources, at the request of the District which had been formed in 1929, conducted an investigation to determine the runoff, waste, stream-channel losses, rates of percolation, and extent and availability of percolation-beds in the Valley, the behavior of ground-water and the relation of normal recharge to draft. The results were published in State Bulletin No. 42, "Santa Clara investigation."

This investigation determined that the ground-water levels had receded 95 feet between 1915 and 1933, which meant a decrease in ground-water storage of 729,000 acre-feet in the 18-year period, or 40,000 acre-feet per year. The normal runoff and waste and the current pumping draft were estimated somewhat lower than Tibbetts and Kieffer's figures, and, although no estimate of total normal percolation was made, it was decided that some source of replenishment other than stream-percolation must exist. This source, in the light of later information, appears to be the clay-blanket of the Valley from which water was being squeezed by compaction as indicated by the settlement of the valley-floor. It also determined that ground-water levels could be restored by conserving the Valley's waste-water and using it to replenish the underground supply.

In 1931, Fred. H. Tibbetts, then Chief Engineer of the District, in his "Report on waste-water salvage project," estimated that the pumping draft during the prior decade had been decreased by low water-levels and high cost of pumping and by unfavorable crop prices in the latter few years. Otherwise, the yearly overdraft would have reached 50,000 or 60,000 acre-feet for the period.

Harry L. Haehl, Consulting Engineer of San Francisco, in a review of this report, estimated that the maximum normal pumping draft would reach 120,000 acre-feet annually and that the maximum normal deficiency of recharge was then about 45,000 acre-feet annually.

In any case, ground-water levels had receded alarmingly, pumping costs were staggeringly high, and conservation measures were plainly needed.

In 1934 and 1936 a $2,400,000 bond issue was voted, and a Public Works Administration grant of $673,000 was obtained, and in 1935 and 1936 the District's water-conservation facilities were constructed. Five storage-dams, controlling 35.7 per cent of the total normal runoff, were built on the major streams of the Valley. Following is the capacity, the drainage and annual normal runoff above the dams, and the per cent of the Valley's total normal annual runoff that originates above the dams:

Table 1--Data on storage-reservoirs

Reservoir	Capacity, ac.-ft.	Drainage area, sq. mi.	Annual normal runoff, ac.-ft.	Per cent of total runoff controlled
Stevens Creek	4,000	16.9	16,700	8.2
Guadalupe	3,500	6.0	3,200	1.6
Almaden	2,000	11.9	6,400	3.2
Calero	9,500	7.2	2,200	1.1
Coyote	30,000	105.0	43,800	21.6
Totals	49,000	147.0	72,300	35.7

Calero Dam stores water almost all of which is diverted from Almaden Creek and is conveyed to storage by an unlined canal 4.5 miles long, having a capacity of 100 cubic feet a second. Almaden Creek has a prolific watershed but no site of sufficient reservoir-capacity, while Calero Creek has a small runoff but a large reservoir-site.

All the dams, with the exception of the Coyote, are the conventional rolled-earth fill type with four-inch reinforced concrete facing upstream and separate reinforced-concrete-lined spillways. The Coyote Dam straddles the recently active Hayward Fault, and for this reason is built about four times as large as any of the other dams. Its central earth roll-fill core is blanketed both upstream and downstream by gravel 10 feet thick at the top and 125 feet thick at the bottom. Outside of these are similar blankets of heavy rock fill. The top width of the dam is 100 to 160 feet, whereas the top width of the other dams is only 20 feet. The heights of the five dams vary from 90 to 130 feet above stream-bed. All the dams have pipes for controlled outlet ranging in diameter from 36 to 50 inches and which are encased in reinforced concrete and laid in the foundation beneath the dams.

Only flood-waters are stored in the dams, and no storage is made until the streams begin to waste into the Bay. Later in the season, when waste has stopped, the stored waters are released to the streams in small flows which can all be absorbed, but which are sufficient to cover the receptive portions of the stream-beds. Both natural-flow and storage-releases are percolated in the natural channels of streams near the rim of the Valley, in ponds constructed by the District both on and off stream, and by spreading on receptive areas off stream.

Percolating works have been built on all but one of the major streams. The Penitencia percolating ponds are along Penitencia Creek at the easterly edge of the Valley. They are off stream and consist of a line of ponds 8,000 feet long, having an area of 4.1 acres. There is no storage on this stream and only natural flow is diverted to the ponds. Since 1936, their first year of operation, the annual amount of water percolated in these ponds has varied from 155 acre-feet in 1939 to 2,400 acre-feet in 1938. They have consistently shown a percolative capacity of 15 cubic feet a second, or 7.3 acre-feet per acre per day.

The Coyote percolating pond is in the stream-bed of the Coyote River just below the Lower Gorge. The pond is formed by an eight-foot high removable flash-board dam with reinforced-concrete floor and abutments. The area of the pond is 32 acres. It percolates natural flow at medium river-stages and storage-flow from Coyote Dam when the natural flow is low or has ceased.

Storage-flow is conveyed hereto by means of the Coyote Canal which heads at the mouth of the Coyote Canyon and is of unlined sidehill construction with a capacity of 100 cubic feet a second. The Canal by-passes the stream-channel in the Coyote Valley in order to avoid more than natural percolation in this valley which is not in the District and where ground-water levels are high.

Since the pond began operating in 1934 its percolative capacity has varied. In 1937 it handled 33.2 cubic feet a second; in 1938, 23.8; and in 1939, 26. It is probable that a high water-table beneath the pond in 1938 caused the low absorptive rate in that year. The capacity of the pond also decreases toward the end of the percolating season. In 1937 it decreased from 34 to 27 cubic feet a second, and in 1938 from 27 to 22. This was probably due to sealing, because in June 1938 the pond-bed was scarified and its absorptive capacity raised from 19 to 26 cubic feet a second. The maximum annual percolation was obtained in 1937 and amounted to 13,900 acre-feet. The minimum was 2,260 acre-feet in 1939.

The Alamitos percolating ponds are at the junction of the Almaden and Guadalupe creeks. They are in the stream-bed and are formed by long, low wire-enclosed gravel "sausages." Their area of 17 acres is partly covered by brush and deep-rooted grasses. They were built by Civil Works Administration and Works Progress Administration labor between 1932 and 1935. Their capacity has averaged 23 cubic feet a second and has varied but little, probably because the water-table here is held fairly constant during most of the year due to the fact that these ponds are in full operation from the time flow starts in early spring until the last of the three dams above the ponds is empty late in the fall. However, some variation is caused by stream-bed sealing. In July 1938 scarification raised the rate from 21 to 24 cubic feet a second. Natural flow is percolated here, and later in the season storage-releases from the Guadalupe, Almaden, and Calero dams. The annual percolation reached 13,300 acre-feet in 1938 as maximum. The minimum of 1,360 acre-feet was percolated in 1939.

The Masson Ditch heads on the Guadalupe Creek about a mile above the Alamitos ponds. It is used to divert both natural flow and storage-releases from the Guadalupe dam to orchard- and vineyard-land upon which the District has been allowed to spread water for percolation during about two months each spring. No percolation-rates have been measured here, but the average annual percolation has been about 1,000 acre-feet except in 1939 when no water was percolated. The area available for percolation has averaged about 20 acres.

Vasona Dam, built in 1935 on the Los Gatos Creek about two miles below Los Gatos and the mouth of the canyon, is a combination detention-, percolation-, and diversion-dam. It consists of two rolled earth-embankments 30 feet high and a center reinforced-concrete spillway 210 feet wide. The storage-capacity of the reservoir is 750 acre-feet and the water covers an area of 79 acres.

Water is diverted to the 75-cubic feet a second capacity unlined Vasona Canal which runs through generally porous ground for 2.6 miles to San Tomas Creek. Water from the Canal is spread for percolation over adjacent receptive orchard-land, and it is percolated also in San Tomas Creek when the flow of the Creek allows it without waste. The average annual percolation from the Canal has been 890 acre-feet, with a maximum of 1,680 acre-feet in 1938 and a minimum of none in 1939.

Vasona Reservoir normally fills and empties several times during a season, the storage being released during periods of low stream-flow and percolated in the several miles of receptive stream-bed below the dam.

Upper Page Ditch diverts from Los Gatos Creek about 1.5 miles below Vasona Dam by means of a low concrete and flash-board diversion-dam. The canal is 1.8 miles long and empties into San Tomas Creek. Here, as at Vasona, percolation is accomplished by spreading the water over receptive orchard-land.

The Ditch also serves three percolating ponds having a total area of 3.3 acres. At the beginning of the 1935 season these ponds absorbed a flow of 5 cubic feet a second, but this rate decreased to 3.0 in 1938, when by scraping a layer of silt off the bottom of the ponds the rate was raised to 4.9. The ponds have percolated an average of 700 acre-feet per year over four years of operation prior to 1939, and over the same period this ditch system averaged 5,390 acre-feet annually with a maximum of 8,616 acre-feet in 1937 and a minimum of 4,000 acre-feet in 1936. The dam and ditch are parts of an old irrigation-system that were purchased by the District in 1932.

The Lower Page Dam, built in 1934 by Civil Works Administration labor, is about 1.5 miles below the Upper Page on Los Gatos Creek. It is a reinforced-concrete diversion-dam with low removable flash-boards that acts also as a percolating dam because it ponds water back over a very porous stream-bed for about one-half mile. It supplies water to the Lower Page Ditch, purchased by the District in 1935 and since then used for irrigation, and for percolation on orchard-ground in the vicinity of Campbell.

For the three years 1935 to 1938 the Ditch has passed an average of 400 acre-feet annually, most of which has probably reached the water-table inasmuch as the area is very gravelly.

These are the only conservation-facilities on Los Gatos Creek, which with an estimated normal runoff of 42,330 acre-feet per year is the second largest stream entering the Valley. The only suitable large reservoir-site on this stream is traversed by a low-level branch main railroad and by an important highway, and the cost of relocating these facilities has prevented the construction of a storage-dam.

Temporary percolating facilities were constructed in 1937 and 1938 in the bed of the Coyote River by throwing up gravel-checks across the stream and thus spreading the water over gravel-flats. In 1937 a section of the stream-bed about 1.5 miles long immediately below the Coyote Percolating Dam was treated in this way, increasing the area covered by water from six acres to 14 acres and increasing the amount of percolation in proportion, the rate of percolation remaining practically constant at 2.1 acre-feet per acre per day. In 1938 approximately the same section was ponded to a greater area than in 1937 but the area and percolating rates were not measured. Only storage-releases were percolated in these temporary ponds because levees could not be built while the stream was flowing, and close regulation of flow was necessary while the ponds were in operation to prevent overtopping and washing out of the levees. In 1937, 4,500 acre-feet were percolated in these ponds between May 12 and November 17, and in 1938, 7,590 acre-feet were percolated between May 20 and December 12.

Stevens Creek is the only major stream with storage that has no percolating works. However, the natural absorptive capacity of the stream-bed is sufficient to percolate without waste the 4,000 acre-feet of storage in about 130 days, which means that the reservoir is empty by the end of September. Guadalupe Reservoir empties in about the same length of time and by the end of September, while Almaden requires only 60 days. Calero Reservoir needs about 145 days to empty and Calero water is usually held until Almaden is empty. In 1938, a wet year, with prolonged stream-flow, Calero release began June 1 and continued with a few short interruptions until December 5. Water from Guadalupe, Calero, and Almaden dams is kept flowing in Guadalupe Creek as far as San José, the end of the receptive stream-bed.

The stream-channel and percolating works below Coyote Dam handle Coyote's capacity in about 230 days. In wet years, release without waste cannot begin before May 1, and the reservoir will not be emptied before January 1. However, since runoff seldom occurs before January 1, Coyote can usually be emptied. In this stream also, water is kept flowing as far downstream as San José.

With the present conservation-facilities, about one-third of the total normal annual percolation of both natural flow and of storage-releases will occur in the District's percolating works and about two-thirds in the unimproved stream-channels. This is the ratio that prevailed during the 1937 season, which was close to normal as to quantity of rainfall and runoff.

The District can be considered to have been in operation for the five years 1935 to 1939, inclusive. However, in 1935 there was no storage and in 1936 Calero and Coyote dams were not complete and, consequently, could not be used to full capacity. A summary of the hydrologic data collected and the conclusions derived therefrom are given in Table 2 for each of the five years of the District's operation.

Column 1 gives the total surface-runoff into the Valley from the tributary watersheds. The percolation resulting from this runoff is given in columns 2 to 4. This percolation is subdivided into natural percolation and percolation induced by the District works. The natural percolation is that due to natural flow in unimproved stream-channels. Induced percolation is percolation of storage in unimproved stream-channels and artificial percolation-ponds, and also that percolation from natural flow which occurs in artificial ponds.

Of the total runoff for the five years, 46.4 per cent was salvaged by natural and artificial means and 53.6 per cent was wasted. During these five years only 44.6 per cent of the total water salvaged can be credited to the operation of the District's works, the remaining 55.4 per cent being natural salvage. Due to the fact that during three of these five years the District did not operate at full capacity, it seems probable that the percentage of the total percolation due to the District's operations will normally be greater than 44.6 per cent.

Table 2--Results of operation of Santa Clara Valley Water Conservation District (1935-1939)

Year	Inflow, acre-feet 1	Percolation Total, acre-feet 2	Percolation Natural, acre-feet 3	Percolation By District's operations, acre-feet 4	Water of compaction, acre-feet 5	Pumping draft, acre-feet 6	Recharge +, overdraft -, acre-feet 7	Recharge +, overdraft -, if Dist. were not operating, acre-feet 8
1935	99,087	70,523	60,153	10,370	15,800	70,900	+15,400	+ 5,100
1936	119,499	82,386	46,238	36,148	9,000	88,600	+ 2,800	-33,400
1937	173,037	102,893	42,487	60,406	5,400	73,900	+34,400	-26,000
1938	420,496	120,630	59,466	61,164	1,500	66,500	+55,600	- 5,500
1939	26,913	25,803	19,130	6,673	0[a]	75,000[a]	-49,000[a]	-55,900
Totals	839,032	402,235	227,474	174,761	31,700	374,900	+59,200	-115,700

Year	Rise +, or drop - of water-level (Nov.-Nov.), feet 9	Rise +, or drop -, if Dist. not operated, feet 10	Rise due to District's operations, feet 11	Average depth to water (Nov.), feet 12	Specific absorption, per cent 13	Actual pumping cost 14	Pumping cost if Dist. not operated 15	Saving in pumping cost 16
1935	+ 7.6	+ 2.5	5.1	131.6	2.0	$597,000	$619,000	$22,000
1936	+ 1.4	-16.7	18.1	130.2	2.0	666,000	729,000	63,000
1937	+14.2	-10.7	24.9	116.0	2.4	583,000	733,000	150,000
1938	+21.6	- 2.1	23.7	94.4	2.6	503,000	743,000	240,000
1939	-21.0[a]	-24.0[a]	3.0[a]	115.4[a]	2.3[a]	578,000[a]	818,000[a]	240,000[a]
Totals	+23.8	-51.0	74.8	.....	2.3	2,927,000	3,642,000	715,000

[a] Figures for 1939 are preliminary estimates based upon incomplete data.

Column 5 gives the contribution to the underground water-supply derived from compaction of aquicludes, and possibly of aquifers. These quantities are obtained by determining the volumetric change during the year as evidenced by sinking of the ground-surface. In order that compaction occurs there must be a decrease in pore-space in the material compacted. This necessitates the squeezing out of an amount of water volumetrically equal to the decrease in pore-space--that is, to the compaction as registered by sinking of the ground-surface.

Column 6 is the record of pumping draft for these five years. The quantities given are total pumping draft--that is, agricultural draft plus the draft by the several water-companies and municipalities. The agricultural draft is determined from records of power-sales for agricultural purposes by the Pacific Gas and Electric Company and the average depth to ground-water level from measurements by the District. The agricultural draft is given by equation (1).

$$\text{Acre-feet draft} = \frac{\text{KWH agricultural power}}{2.56 \times (\text{depth to water} + 35')} \tag{1}$$

Equation (1) is based upon the assumptions that the overall efficiency of pumping plants is 40 per cent, that 35 feet must be added to the average depth to water to cover draw-down, height of delivery above ground, etc., and that the power-load is distributed uniformly over the area under consideration. Since the records of power-sales furnished by the Pacific Gas and Electric Company do not include the Coyote Valley, an estimate of the pumping draft in this area was made by assuming the same duty for water each year that existed in the main Valley. The remainder of the total draft is made up of the draft by the San José Water Company, Campbell Water Company, cities of Santa Clara, Sunnyvale, and Mountain View, plus 1,000 acre-feet per year to cover the many smaller water-companies throughout the District.

Column 7 gives the annual recharge or overdraft. This is equal to the total percolation plus the increment from compaction minus the pumping draft. Although the records of agricultural power-sales are not available for 1939, an estimate has been made of the overdraft. The estimated value seems reasonable because, due to the dry character of the year, the irrigation-requirements were large and the percolation was small.

The overdraft which would have occurred during the five years 1935 to 1939 had the District not been in operation is given in Column 8. This overdraft is equal to the pumping draft, minus the natural percolation, minus the increment from compaction. It is interesting to note that there would have been an overdraft even during the wet years of 1937 and 1938 if the District had not been operating. The fact that there was no overdraft in 1935 is due to the large contribution by compaction.

Column 9 gives the average fluctuation of the water-level in the Valley during the five years 1935 to 1939. The average fluctuation is the difference between the average water-levels at the low points of the two consecutive years. These average water-levels are computed from the records of water-level in about 250 wells throughout the Valley.

The fluctuation of the water-levels that would have occurred if the District had not been operating is given in column 10. Due to the annual overdraft that would have existed (see col. 8) the average water-level would have dropped each year, except in 1935 when there would have been a small recharge. This annual drop is computed by assuming that the fluctuation if the District had not operated bears the same relationship to the actual fluctuation that the annual recharge or overdraft that would have occurred bears to the actual overdraft or recharge. The total drop for the five years would have been 51.0 feet.

Column 11, the rise attributable to the District's operation, is equal to the difference between the actual fluctuation and the fluctuation that would have occurred without the District--that is, column 9 minus column 10. Although the actual rise during the five years 1935 to 1935 was only 23.8 feet, the District was responsible for a rise of 74.8 feet because without the District's works there would have been a drop during these four years of 51.0 feet.

Column 12 is a record of the average depth to water-level in November of each of the five years. It is interesting to note that if the District had not been in operation the average depth to water would have increased from 136.7 feet in 1935 to 190.2 feet in 1939, whereas it actually decreased from 131.6 to 115.4 feet.

Column 13 gives the specific absorption for each of the five years. These values represent the average specific absorption of the alluvium, and are based upon the volume of material saturated by the measured rise in water-levels and the recharge. The former artesian area of the Valley was excluded from these calculations because it is assumed that changes in water-levels in this area do not represent changes in storage but merely a change in pressure in confined aquifers. The average value of 2.3 per cent is much lower than that arrived at by previous investigations in this Valley. William O. Clark in United States Geological Survey Water-Supply Paper 519, "Ground water in Santa Clara Valley, California," estimated the "water-yielding capacity of the alluvium" to be approximately 12 per cent. E. N. Bryan in Bulletin 42, Division of Water Resources, State of California, "Santa Clara investigation," stated that "The specific yield in the alluvial fill as thus determined varies between 7.3 per cent and 12.1 per cent in different zone groups, with an average for the whole valley somewhat lower than estimated in Water-Supply Paper 519 of the United States Geological Survey and in the Tibbetts-Kieffer report." The Tibbetts-Kieffer report gives a value for the "available porosity" of 11.1 per cent. These former estimates were based upon drillers' logs of wells in the Valley, a method which is open to considerable criticism.

Columns 14 and 15 give the actual pumping cost and the estimated pumping cost if the District had not operated. The figures for actual cost are based upon the revenue derived from sales of agricultural power by the Pacific Gas and Electric Company. In order to determine what the pumping costs would have been without the District in operation, the amount of power necessary to pump the same amount of water that actually was used at the depth that would have existed was calculated. The cost for this amount of power was computed using the actual average cost per kilowatt-hour.

The difference between the figures in column 15 and in column 14, given in column 16, represents the savings in pumping costs. The total for the five years of $715,000 represents a saving of approximately 20 per cent in power-bills.

Prior to the time the District started operating the average depth to water-level increased from 30 feet in 1916 to 137 feet in 1934. During this period it seems evident from an inspection of the curves at the top of Figure 1 that in a year of normal rainfall there has been sufficient recharge to take care of the pumping draft and natural losses during that year. This is due to the fact that during wet years the pumping draft is low. Over a period of years the natural replenishment is not sufficient to supply the average annual pumping draft. The average normal replenishment has been estimated to be about 76,000 acre-feet (Tibbetts and Kieffer Report, 1921), and the average annual pumping draft with the present development of the Valley approximates 105,000 acre-feet. Thus, without artificial replenishment, there could not be any appreciable rise in the water-level even from a series of wet years.

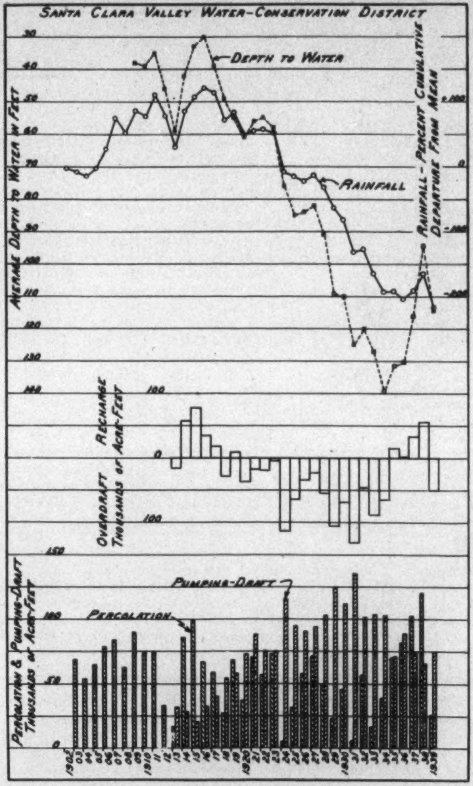


Fig. 1

The effect of artificial replenishment can be seen in the latter portion of the water-level curve. The rise in water-levels during 1937 and 1938 is much greater than in any year of comparable rainfall in the past.

The bar graphs at the bottom of Figure 1 give the pumping draft and percolation for each year for which records are available. The results are open to considerable criticism in that very few percolation-measurements were made prior to 1935, and values for most of the past years had to be estimated. Since 1935, however, complete percolation-measurements have been made. Therefore, the results since the District has been in operation are as reliable as can be obtained.

The bar graph at the center of Figure 1 shows the overdraft or recharge occurring during the past 26 years based on the pumping draft and percolation given at the bottom of Figure 1. Consequently, the accuracy of this graph is the same as for the lower graph. Furthermore, there is an error in these values due to the fact that the water of compaction has not been taken into consideration prior to 1935. This makes the overdraft for the years prior to 1935 too high. These figures can be corrected as soon as more information is obtained concerning

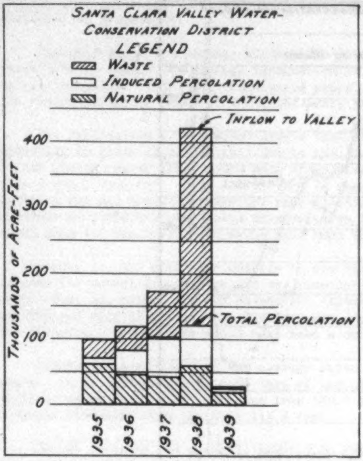


Fig. 2

this phenomenon.

The annual saving given in column 16 of Table 2 is only the saving in power-cost. Besides this, however, there has been a large saving in capital investment in pumping plants brought about by the rise in the water-level. This is due to the fact that, if the depth to water-level had continued to increase as previously mentioned, it would have necessitated the deepening of many wells and the lowering of pumps in most wells. The additional expense for this work cannot be determined, but it probably would have amounted to several hundred thousand dollars. Therefore, the total saving during the five-year period, 1935-1939, brought about by the District's operations, has approximated a million dollars.

Santa Clara Valley Water Conservation
District,
San Jose, California

DISCUSSION

PAUL BAUMANN--This discussion is centered on one feature mentioned but not elaborated on by Mr. Hunt, namely, the influence of a high water-table on spreading from basins. He refers to the Coyote percolating pond which in 1937 absorbed 33.2 cubic feet a second while in 1938 its capacity dropped to 23.8. The wetted area is 32 acres.

Apparently the water-table beneath the pond was higher in 1938 than in 1937. According to Figure 1 the average depth to water-level decreased from a maximum of about 122 feet in 1937 to a minimum of about 94 feet in 1938. The conditions beneath the Coyote pond are not shown specifically but in all probability there the depth to water-level was less than the average. Otherwise it is doubtful if the rise stated would have affected the rate of percolation to the extent as previously mentioned, that is, by a reduction to some 72 per cent.

Experience gained by the Los Angeles County Flood Control District during spreading operations in off-channel basins on the Rio Hondo indicates that the depth to water-level does not appreciably affect the rate of percolation unless this depth is much smaller than the average depth for the Santa Clara Valley Water Conservation District would indicate. The Rio Hondo Basins are mentioned because of apparent similarity to the Coyote pond. They consist of seven basins with an aggregate wetted acreage of 40 and an average percolating capacity of about one cubic foot a second per wetted acre.

At the beginning of our spreading tests in 1937 the water-table stood 25 feet beneath ground-surface at the basins.

The initial rate of percolation was nine cubic feet a second per wetted acre, but it dropped to two at the end of three days.

Within this period the ground-water immediately beneath the basins rose to within four feet of the beds. During this rapid rise the expulsion of air from the voids was noted. The above-mentioned four-foot distance probably coincided with the capillary rise of water in this soil.

The water-surface in a well 200 feet east of the basins rose slowly, the difference in elevation of the two water-surfaces at the end of the three-day period being 18 feet. When this position of the ground-water mound was reached, there was an abrupt change in the rate of decline in percolation-rate and the further decline to 0.9 cubic foot a second per wetted acre extended over a period of 20 days. At that time the water-surface in the easterly well was 5.5 feet lower than that beneath the basins which was then 1.5 feet beneath the basin-bed.

Dewatering two basins adjacent and downstream from the one under observation had the effect of lowering the apex of the mound beneath it by 0.6 foot, the water-level in the easterly well by 1.0 foot, and increasing the percolation-rate to 1.5 cubic feet a second per wetted acre. Upon introducing water again into the adjacent basins the conditions of percolation and ground-water became the same as before the dewatering.

The observation-basin was then dewatered, dried, and cultivated. Upon applying water subsequently the basin was filled to approximately 0.5-foot greater depth than formerly.

The percolation-rate increased to 2.0 cubic feet a second per wetted acre, the apex of the ground-water mound rose to contact the surface-water in the basin, and the water-level in the easterly well rose 1.0 foot higher than formerly.

It is believed that the scarification of the basin caused a freer movement of the water into the soil, thus causing the mound to merge with the surface-water in the basin. Under those conditions the depth of water in the basin--approximately three feet--became effective in increasing the mound-pressure.

The shape of the mound is governed by the depth to and slope of the ground-water and the porosity of the ground. The pore-size and shape is important. The curvature of the outer surfaces of the mound in reasonably homogeneous soil is generally parabolic. It is more acute with small depth and small porosity than with great depth and great porosity. Its limits lie between a vertical and a horizontal line. The former for wide open pores (cascading) and the latter for tight or impervious soil (pounding).

The curvature is due to turning of water-filaments from a vertical to a horizontal or near horizontal direction. This is due to internal pressure. The internal pressure is a maximum along the axis of the mound and a minimum (atmospheric) at the outer surface. Since the ground-water fills the voids of the soil completely, any additional water, such as due to spreading, must necessarily occupy space above the ground-water table and must initially flow along its surface. The acceleration of the ground-water particles due to the pressure of the mound requires time. Hence, the rate of percolation tends to increase with sustained mound-pressure once the system has attained equilibrium due to the steepening of the gradient.

Careful attention should be given to the influence of the mound in all spreading projects as it may materially affect the rate of percolation, that is, the absorption-capacity. This is particularly true of spreading in relatively tight soils with high water-tables. Clay-lenses causing perched ground-water may produce the same effect locally.

GROUND-WATER, SALT-WATER INFILTRATION, AND GROUND-SURFACE RECESSION IN SANTA CLARA VALLEY, SANTA CLARA COUNTY, CALIFORNIA

C. F. Tolman and J. F. Poland

The Santa Clara Valley Water Conservation District includes 138,000 acres of the Santa Clara Valley, California, of which 120,700 acres are cultivated lands, roads, and cities which are watered by approximately 2,000 pumping wells. During the period of deficient rainfall, 1916-1934, prior to Santa Clara Valley Water Conservation District's spreading operations, the average water-level in wells dropped about 108 feet.

Attention of those interested in ground-water conservation has been focussed on this area because of the successful organization of the Santa Clara Valley Water Conservation District, the recovery of water-level due to water-spreading operations, the contamination of ground-water around San Francisco Bay, and the sinking of land-surface over an area of about 200 square miles, forming a trough-like depression with maximum lowering in 1937 at San José of 5.57 feet.

The geology and ground-water hydrology of this area have been described repeatedly. This paper summarizes briefly the geology of the Santa Clara Valley, especially of the clay-deposits which constitute approximately 70 per cent of the alluvial deposits and which are responsible for ground-water confinement [see 1 of "References" at end of paper], discusses ground-water contamination and its cause, and contains a description to date of ground-surface movements with an explanation of the cause of these movements.

Geology

Topography--The Santa Clara Valley is a great structural trough extending from Yerba Buena

Island just east of the Golden Gate southerly to and including the Hollister Valley (Fig. 1). Farther south this same structural depression is occupied by the San Benito River. The Santa Clara Valley encloses the southern portion of San Francisco Bay, and the fringing swamp-lands.

The southern portion of the Santa Clara Valley is tapped by the antecedent Pajaro River and its tributary, Llagas Creek, which drains the southern portion of the Santa Clara Valley up to the divide between San Francisco Bay and Monterey Bay. The divide lies on the upper Coyote fan, which apexes at the mouth of the Upper Coyote gorge, through which the Coyote River debouches from the mountains.

In the immediate geologic past the Coyote River has shifted on its fan, at times discharging northerly into San Francisco Bay, as at present, and at times taking the course of Llagas Creek and Pajaro River, and discharging into Monterey Bay. This was discovered by the study of fresh-water fishes in streams discharging into San Francisco Bay and Monterey Bay [2]. The lower gorge of the Coyote River lies just north of Coyote between Tulare Hill and the main range to the east. The mouth of this gorge is the head of the lower Coyote fan, which constitutes the most favorable spreading-area for the Coyote River. This fan extends to and west of the Santa Teresa hills. The narrow and steep valley between the Santa Teresa hills and the main range is locally denominated "The Narrows," and north of these narrows the influent seepage of the Coyote River is small.

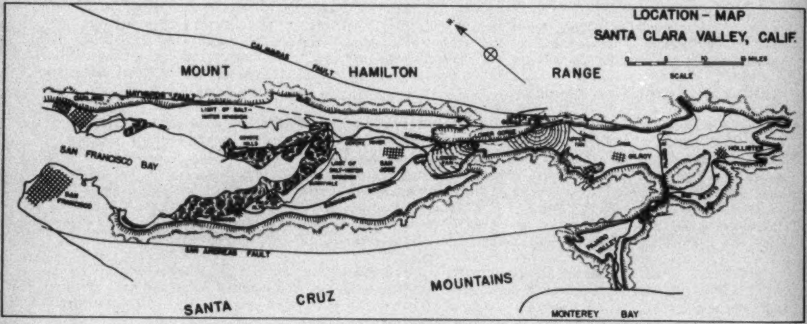


Fig. 1

There has been considerable speculation as to whether an earlier Sacramento River occupied the Santa Clara Valley and discharged into Monterey Bay, which is a large submarine canyon, prior to the marine invasion which produced San Francisco Bay. The depth to bed-rock at various points, such as at the lower narrows, and the absence of large river-terraces, have been cited against this hypothesis, but, as will be emphasized later, the Santa Clara area has since Tertiary times undergone repeated earthquake-movements and changes in level, and the present depth to bed-rock is not a criterion of depth to bed-rock and the slope of the Santa Clara Valley in the past.

The Santa Clara Valley is bounded by the Santa Cruz Mountains on the southwest, and the Mount Hamilton Range on the northeast. The margins of the two elevated blocks are truncated by the active earthquake-faults of the San Andreas fault-system. The Haywards fault and the Sunol or Calaveras fault join south of Gilroy, and farther south the Haywards fault joins the well-known San Andreas fault. The latter truncates the Santa Cruz Mountains a few miles southwest of the valley-plain.

The topography of the two ranges is typical of the Coast Range. In places remnants of longitudinal valleys are preserved which antedate the last uplift. The most prominent of these are the structural valleys developed along portions of the San Andreas, Haywards, and Calaveras faults.

The most striking feature of both ranges is an old rolling and hilly topographic surface, well developed in the center of the ranges. The present cycle of erosion has cut deep canyons and valleys into this old surface, but large areas are preserved in the center of the ranges, and remnants of this surface can be seen extending down the main ridges between the steep valleys on the mountain slopes. Dr. Bailey Willis first recognized that the earlier topographic surface of most of the Coast Ranges was arched, with apex at the center of the ranges and sides preserved on the main ridges between individual drainage-systems.

A preliminary study of the area of this old surface and the quantity of material eroded by the rejuvenated drainage indicates that the amount removed by erosion subsequent to the last uplift of the mountains represents only 100 to 200 feet thickness of deposits underneath the valley-floor. As the alluvium in the Santa Clara Valley has been penetrated to the depth of 1,500 feet in the deepest well, and depths approaching 1,000 feet in many wells, the conclusion is reached that the alluvium of the Santa Clara Valley has been derived in part from the erosion of older Santa Cruz and Mount Hamilton mountains, and only in small part from the erosion of the present ranges since the last uplift.

Attention will be limited in this paper to the Santa Clara Valley Water Conservation District. The location of this District between the lower Coyote narrows on the south, and the line running northeasterly and then easterly across the southern end of San Francisco Bay east of Palo Alto, is shown in Figure 4.

Geological formations of the mountains--The geological formations of the mountain blocks may be enumerated as follows: (1) Granite (chiefly granodiorite); (2) Franciscan formation; (3) Cretaceous and Tertiary marine formations; (4) Santa Clara formation.

(1) Granite--The granite is exposed in the Santa Cruz Mountains. It is outside the drainage-area of the Santa Clara Valley, and therefore is not important as a source of at least the upper portion of the alluvial deposits in the Santa Clara Valley.

(2) Franciscan formation--The Franciscan formation covers most of the Santa Cruz Mountains tributary to the southern portion of the Santa Clara Valley, and crops out in the central portion of the Mount Hamilton Range. The formation consists predominantly of dense argillaceous shale, with some flinty organic shale and fine cemented sandstone, one horizon of foraminiferal limestone, and many basic intrusions, largely serpentine in character. The weathering and erosion of these formations develop clayey alluvium with minor cherty gravel.

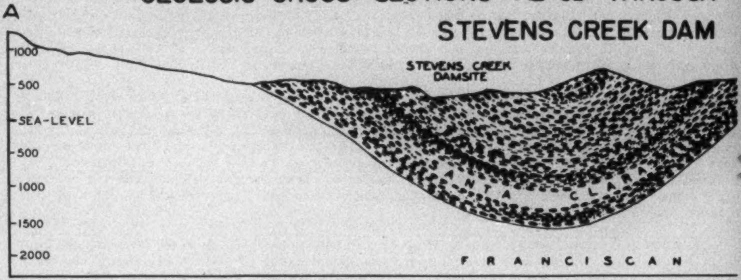
(3) Cretaceous and Tertiary marine formations--The marine sedimentary series from Cretaceous to Late Tertiary in age reaches an aggregate maximum thickness of 30,000 feet in the Santa Cruz Mountains, and a somewhat thicker sequence of formations crops out in the Mount Hamilton Range. Only a small portion of the area of the Santa Cruz Mountains tributary to the Santa Clara Valley Water Conservation District is covered with these formations. On the eastern side, however, Tertiary marine sandstone is abundant, and the eastern portion of the Conservation District, therefore, contains a more sandy alluvium than the western portion.

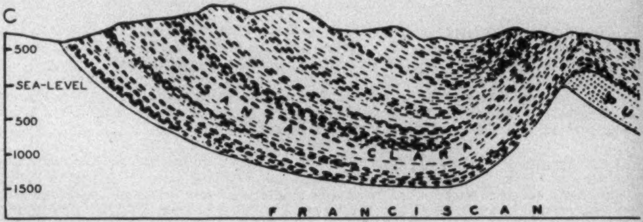
(4) The Santa Clara formation--The Santa Clara formation is described more in detail than the earlier formations on account of the erroneous conclusion in former reports that it constitutes the lower portion of the alluvial deposits of the Santa Clara Valley, and was designated as "the older alluvium."

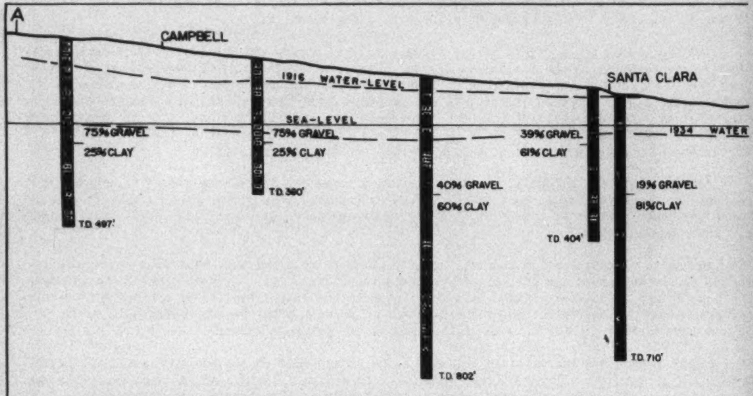
The Santa Clara formation consists of silt-cemented conglomerate, fine silt-cemented sandstone, siltstone, and claystone, all of moderate induration. It is evenly and well bedded near the base of the formation. It was laid down prior to the last elevation of the Santa Cruz Mountains as shown by the truncation of the Santa Clara formation by the old topographic surface. It was also deposited prior to some of the folding of the range itself.

Figure 2 presents two detailed cross-sections at and east of the Murphy Damsite on Stevens Creek, and depicts the folding of the Santa Clara formation. In this section the exposed Santa Clara formation is about 2,500 feet thick. The hydrologic characteristics of this formation have been determined by tests made at the Murphy Damsite, and by pumping tests of wells in the foothill-district west of the Valley. The tests at Murphy Damsite [3] give a maximum permeability (parallel to stratification) of four [4] for the entire Santa Clara formation exposed in the cut-off trench, and a permeability of eight for the gravel-strata of this formation. Pumping tests in the foothills near Los Altos where small domestic wells penetrate the Santa Clara formation indicate an average permeability of one to ten. In contrast, the pumping tests of wells penetrating the alluvium indicate a permeability of less than 100 to as much as 3,000.

GEOLOGIC CROSS SECTIONS AB-CD THROUGH STEVENS CREEK DAM


A
1000
500
SEA-LEVEL
500
1000
1500
2000
STEVENS CREEK DAMSITE
SANTA CLARA
FRANCISCAN


C
500
SEA-LEVEL
500
1000
1500
SANTA CLARA
FRANCISCAN


A
CAMPBELL
1916 WATER-LEVEL
SANTA CLARA
SEA-LEVEL
1934 WATER
75% GRAVEL
25% CLAY
T.D. 497'
75% GRAVEL
25% CLAY
T.D. 380'
40% GRAVEL
60% CLAY
T.D. 802'
39% GRAVEL
61% CLAY
T.D. 404'
19% GRAVEL
81% CLAY
T.D. 710'

GEOLOGICAL SECTION A-B FROM CAMPBELL TO ALVISO
SHOWING
PERCENTAGE OF GRAVEL AND CLAY IN WELLS

12 MILES

SANTA CLARA FORMATION

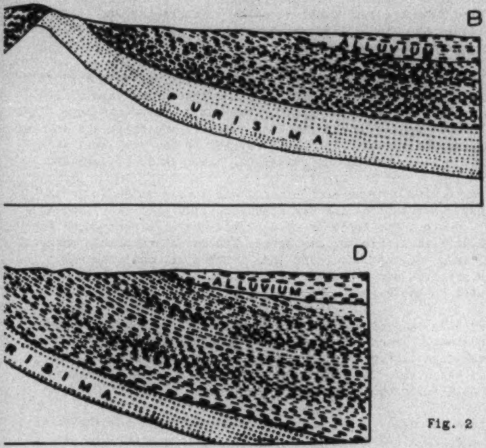


Fig. 2

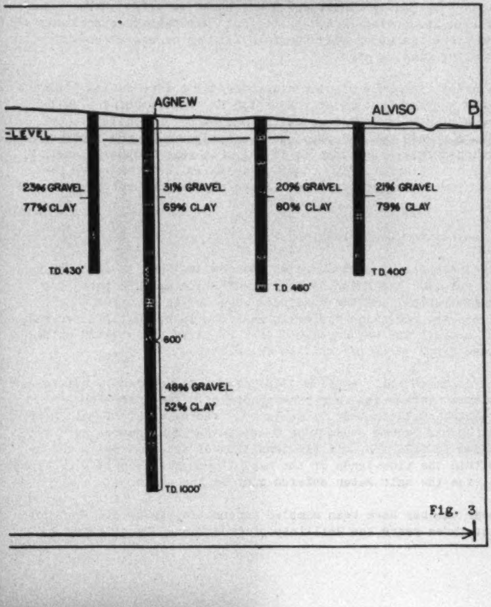


Fig. 3

In all previous descriptions of the geology and hydrology of the valley [5] the marginal belt of Santa Clara formation has been designated as "the older alluvium" and the writers have not recognized the existence of a broad area of the Santa Clara formation at shallow depth along the western boundary of the District. The clay-content of this older alluvium has been supposed to be due to weathering, as has been described for the alluvial cones of Los Angeles Basin [6]. The finer portion of the formation consists of unweathered silt and is not derived from the weathering of the material since it was laid down. This is mentioned because the building of the Stevens Creek Dam was delayed by an unfavorable report on the suitability of the Damsite based on the supposed weathering and hence unsound character of the bed-rock.

The Santa Clara formation crops out in the foothills west of the valley from Palo Alto on the north to Los Gatos on the southwest. The northern portion of this outcrop averages about one mile in width and the southern half approximately two miles in width. In addition, several square miles of Santa Clara formation occur within the valley overlain by a cover of shallow alluvium. The portion within the valley proper has been included in the alluvial water-holding basin of the Santa Clara Water Conservation District. It should not be thus included, and estimates of specific yield have been based on the incorrect assumption that this material has been dewatered by pumping in the Santa Clara Valley.

The Santa Clara formation has not been identified in any of the materials examined from deep wells. This examination, however, is far from complete, especially for the lower portions of the deep wells, and it is possible that the deep well in San José (1,500 feet) and other deep wells may have encountered this formation. We hope to have more data after we examine the complete set of samples of two deep wells in San José, recently drilled under rigid control.

Alluvial deposits--The alluvial fill of the Santa Clara Valley is characterized by large percentage of clay-layers. In general, the clay designated by the drillers as blue clay is the equivalent of the clays now being deposited in the Bay of San Francisco and its marshlands. Brown and yellow clay, as distinguished from the blue clay, is silty in character and is deposited largely by rainwash, flood-overflow, and wind. The latter is caught by vegetation, especially in those areas where saturation reaches ground-surface.

Figure 3 is a section across the Campbell Creek alluvial cone and extending to Alviso in the slough-area of San Francisco Bay. The first two wells show 75 per cent gravel and 25 per cent clay. The next two wells show approximately 40 per cent gravel and 60 per cent clay. The logs of the remaining wells, all situated within the sinking area classify the materials as nearly 80 per cent clay and 20 per cent sand and gravel. The one exception is the deep well at Agnew (1,000 feet) which penetrates into a lower horizon of alternate, clay, sand, and gravel.

In the Bay region north of Mountain View, one horizon of sand and gravel is shown in the well-logs at a depth from 20 to 50 feet, overlain by the San Francisco tide-land clay, and a second at a depth of 160 to 200 feet. Both these horizons of sand and gravel extend under the San Francisco Bay, as shown by wells drilled within the bay-area. The structure of the water-bearing alluvial deposit, therefore, is a "depositional syncline," with apex under the bay. The sand and gravel in the center of the syncline was deposited by the Coyote River drainage when the Santa Clara Valley was not occupied by the bay.

Over-pumping, especially at Palo Alto, has drawn down the pressure-gradient until the slope is from the center of the bay southwestward toward the Santa Cruz Mountains. The wells in this area are pulling water from the gravel-deposits under the bay, and if the thick upper layers of clay had not been penetrated by wells which were later allowed to fall into disrepair, there probably would have been no serious salt-water contamination in this area.

The original artesian area where water stood at or above ground-surface has been arbitrarily taken by Clark, Tibbetts, Conkling, and Bryan [7] as the boundary of confined water, and for the purposes of calculating specific yield water-table conditions are assumed to exist in the strata outside this area. We believe that this assumption is not justified. Water-table conditions exist only in a narrow marginal zone where the upper clay-layer is lacking or where the water-level has been drawn down below the upper clay-stratum.

The study of well-logs and the great abundance of blue clay over the entire valley lead the writers to believe that the valley was sinking throughout the period of deposition of alluvial material. Bay- and swamp-clays were at times laid down up to the margin of the valley-floor. Confinement, therefore, extends up to a narrow band adjacent to the periphery of the floor of the valley. The only known and developed free-water body is in the area near Campbell, and a portion of this area is capped with a clay-blanket [8]. Inasmuch as water-level has been lowered below this cap, the ground-water functions as free ground-water rather than confined ground-water.

Salt-water contamination

In 1907-08, Mitchell [9] analyzed samples of surface water and samples from 12 deep wells close to the Bay. Only one of these samples, the chloride-content of which was 228 parts per million, showed local salt-water contamination, and the remainder were low in chloride. Omitting the three highest chloride-values, the range for the wells was from 15 to 40 parts per million chlorides. Water from the well nearest the bay contained only 27 parts per million chlorides; this same well in 1929 contained 3,000 parts per million chlorides.

In 1915, the water-level in the artesian wells at Palo Alto dropped to sea-level, due to municipal pumping, although in the Santa Clara Water Conservation District the water-level reached its high point in 1916. By 1920, contamination of wells near the bay east of Palo Alto was reported, and in 1928 the condition had become so serious that various conferences were held to study the situation. It was decided to fill and seal the long line of artesian wells dug by the Spring Valley Company in 1904 within the tide-lands of the bay. These had been left uncapped, the casings had rusted, and at high tide the salt water entered many of the wells.

Since 1929 some of the wells near the bay have been sampled intermittently by Stanford University students, and during the past three years the Well Inspector of Santa Clara County and engineers of the Federal Land Bank have taken systematic samples from wells on each side of the bay. From these data the present area of salt-water invasion has been plotted on Figure 1. Water containing more than 100 parts per million of chlorides is considered contaminated in this area and the boundary was drawn between the wells showing less than and those showing more than 100 parts per million of chlorides. These studies show that the main source of contamination is movement of salt water through the abandoned wells within the bay-area. As shown by the high-chloride boundary-line, contamination extends farthest inland in the gravel-deposits of streams discharging into the bay, indicating that shallow gravels below and contiguous to present stream-channels constitute a second means for encroachment of salt water under present lowered ground-water levels. Additional contamination is attributed to breaking of the clay-seal during the construction of Dumbarton Bridge and the new Hetch-Hetchy pipe line which crosses the bay. This conclusion has not been checked, although some wells near the bay became contaminated a few years subsequent to these operations.

At the present time severe contamination is restricted chiefly to the gravels within the top hundred feet below ground-surface. The prevalent clay-member, which is found in the zone from 60 to 170 feet below sea-level, is impervious and acts as a seal against downward movement of the salt water except where pierced by wells. A large number of wells puncture this clay-body within the contaminated area, however, and many of these are perforated in the shallow contaminated zone as well as at greater depth. These wells should be plugged to prevent salting of the deeper aquifers, and those pumped at present should be repaired to exclude the near-surface salty water, because during the large part of the year these wells stand idle, and downward circulation of salt water continues at a rapid rate.

It will probably be difficult to seal completely all the wells within the tidal lands, and advance of contamination will probably be checked completely only when and if water-recharge in the District brings the water-level in the wells above sea-level. It will be very difficult, if not impossible, to remove by recharge any salt water which enters the lower aquifers in the meantime.

Ground-surface movement [10]

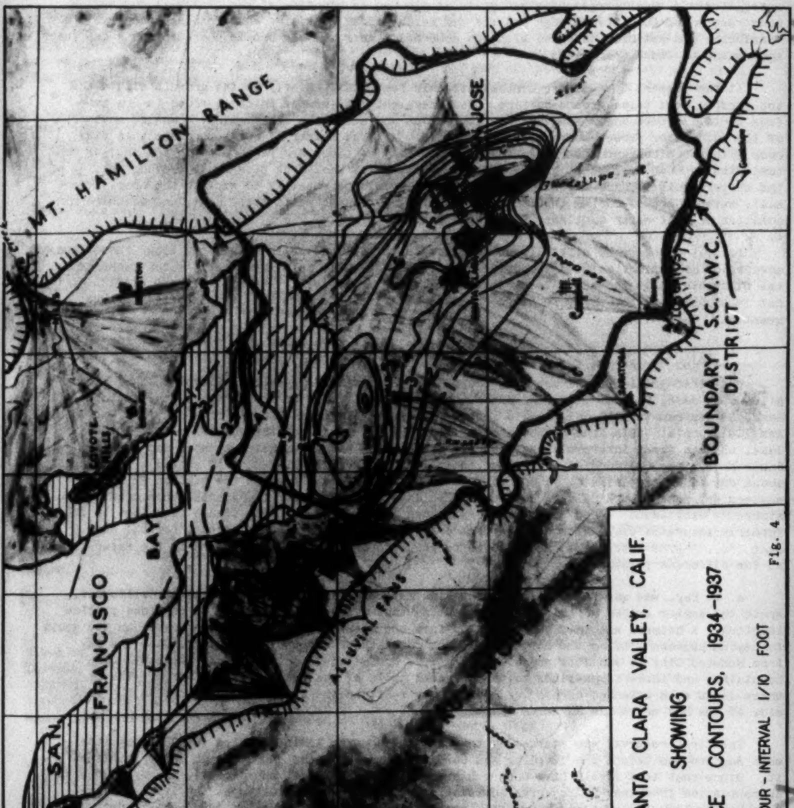
The first precise level crossing the sinking area was surveyed from Bingham (Utah) through Niles, San José, Redwood City, and San Francisco. The portion of the survey in the vicinity of San José was run in 1912. In 1920 a second precise leveling was carried from San José to Santa Ana, California. This line showed a discrepancy of 0.4 foot from the earlier survey at San José, and was first interpreted as a survey-error which was distributed between San José and Santa Margarita, California. The first releveling occurred in 1932-33, and showed a lowering of about one inch at Redwood City; 0.5 foot at Palo Alto; and 4.1 feet at the station P7 at the eastern entrance of the Hall of Records in San José. This extraordinary subsidence created considerable excitement. Fred H. Tibbetts explained it as follows: "The change in volume in the formerly saturated clay which has now been drained [by pumping] should account for the settlement . . . . [The settlement] seems to be roughly proportional to the decline in the water plane at the different points."

A. L. Day, who was interested in measuring movements on the active faults of California, wrote the senior author of this paper suggesting that every effort be made to continue precise leveling. A network was laid out extending from the main survey-line between Coyote on the south to beyond Redwood City on the north. This net consists of a main Y extending around the bay from Redwood City to San José and Niles, and five cross-lines to the edge of the Santa Cruz Mountains, and three cross-lines to the marginal hills of the Mount Hamilton Range. Two of these lines were extended across the San Andreas fault on the west, and the three on the east side of the bay cross the Haywards fault.

The first resurvey was started by the California Works Administration in 1932, but this work was dropped before the leveling was completed and the Coast and Geodetic Survey finished it. Since that time levels have been run every year by the Coast and Geodetic Survey, aided by appropriation from the Public Works Administration, and in three instances the levels of the main Y have been run a second time after the completion of the survey of the complete net.

The available data are sufficient to permit the drawing of subsidence-contours since 1934, and those between 1934 and 1937 are shown in Figure 4. These indicate an oval-shaped depression with a hole in the vicinity of San José, and a second hole just north of Synnyvale. The boundary of the subsidence-area is indicated fairly well by the 0.1-foot contour, and this area encloses the original artesian area on the west side of the valley and corresponds to the area in which the deposits of bay-clay are best developed. It does not include the area where maximum water-table lowering has occurred, in the vicinity of Campbell, California, where the material is predominantly gravel with minor clay, and where water-table conditions exist.

Figure 5 is a cross-section from Redwood City to Coyote showing the ground-subsidence from 1912 to 1938. This shows the two holes of maximum ground-surface depression at San José and at Moffett Field east of Sunnyvale. The maximum sinking at P7, San José, is 5.57 feet. A cross-section between Los Gatos and Alum Creek (Fig. 6) depicts the narrow trough-shaped character of the depression.


MT. HAMILTON RANGE
JOSE
Guadalupe Ck.
COYOTE HILLS
BAY
SAN FRANCISCO
ALLUVIAL FANS
BOUNDARY S.C.V.W.C. DISTRICT

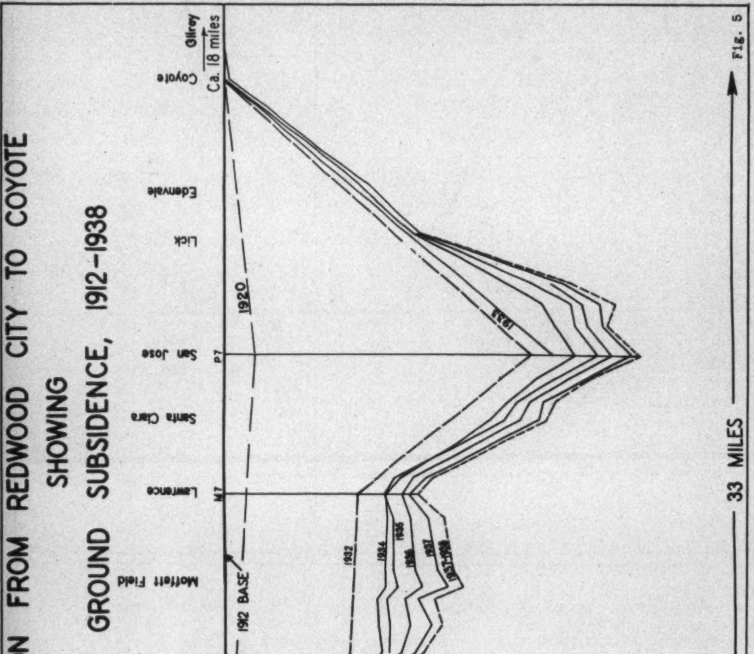
MAP OF SANTA CLARA VALLEY, CALIF.
SHOWING
SUBSIDENCE CONTOURS, 1934-1937
CONTOUR-INTERVAL 1/10 FOOT
Fig. 4

From plotted rainfall, average water-level of the District, and subsidence of bench-mark P7 at San José, the recovery of water-level since 1934, due in part to the spreading operations of the District, is shown to coincide with a decrease in the rate of subsidence. There has been practically no subsidence from 1937 to 1939. In fact, the uncorrected surveys for 1939 indicate a slight rise of ground-surface coincident with the large recovery of water-level in 1938 and a slight sinking due to the lowering of water-level during the dry period of 1938. However, these surveys have not been checked, and the actual rise of ground-surface has not as yet been proved.

Summary of data available to date--

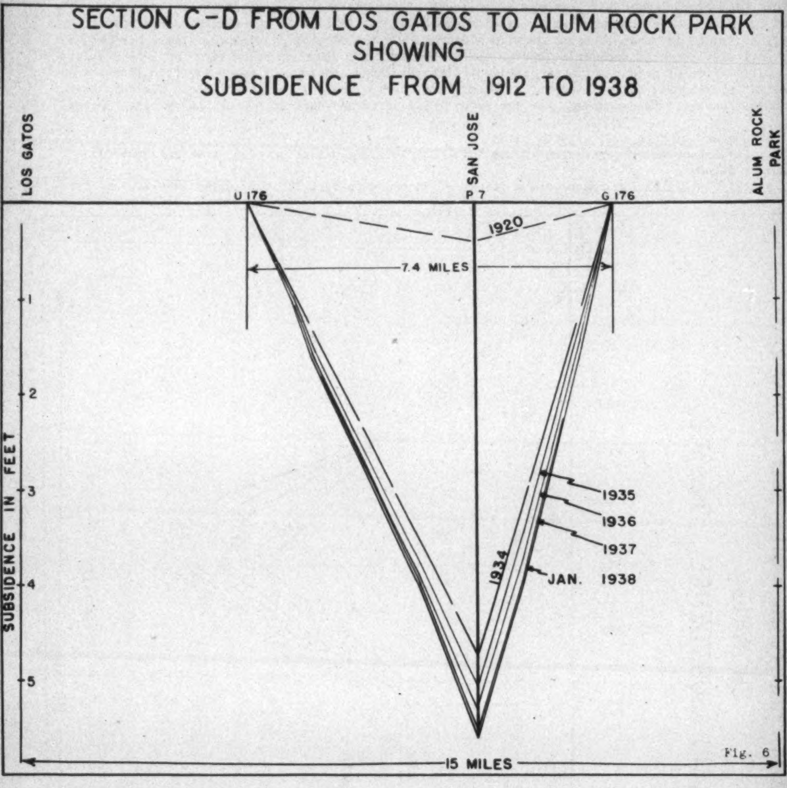
(1) Ground-water depression in the Santa Clara Valley has affected an area of about 200 square miles.

(2) The depression represents a volume of 44,480 acre-feet for the period 1934-37, and for



SECTION FROM REDWOOD CITY TO COYOTE SHOWING GROUND SUBSIDENCE, 1912–1938

Fig. 5



SECTION C-D FROM LOS GATOS TO ALUM ROCK PARK SHOWING SUBSIDENCE FROM 1912 TO 1938

Fig. 6

the period 1919-37 of 232,000 acre-feet, which is approximately 15 per cent of the quantity of water pumped during these periods.

(3) The sinking is limited to areas underlain by dense blue clay.

(4) No sinking has occurred within areas where water-table conditions exist, or in areas underlain by more than 40 per cent of sand and gravel.

(5) The areas of maximum sinking contain deep wells (two at Moffett Field 1,000 feet deep, and one in San José 1,500 feet deep, and others 1,000± feet deep).

(6) The areas of maximum sinking are areas of maximum well-production.

(7) The "rising" of casings is common in the sinking area. Many of these casings have risen two to three feet above ground-surface. This rising registers the compaction of materials between bottom of well-casing and ground-surface.

(8) Sinking of ground-surface virtually ceased in 1937, three years after spreading operations were initiated by the Santa Clara Water Conservation District, and after a rise in average water-level of approximately 50 feet.

(9) In 1938-39 there has been a drop of well water-levels. This rise and drop of water-level is reflected by a rise and drop of land-surface, as indicated by the uncorrected survey-

levels. However, this change in level is not to be accepted until the surveys are checked and adjusted.

(10) No significant ground-movements have been detected along the San Andreas and Haywards faults. The survey-lines show small but irregular ground-elevations to the east of Haywards fault, but these are too small and too irregular to be considered indicative of earth-movements along that fault.

Explanation of sinking--The nature of the process of compaction and the effect on ground-surface may be illustrated by a simple experiment of Terzaghi [11] and by the application of the principles governing the volume-equilibrium in this experiment to actual conditions resulting from the reduction of pressure in the aquifers caused by pumping.

Terzaghi placed saturated clay in a cylinder without outlets and applied pressure by means of a piston. The material was compressed slightly but on relief of pressure recovery of volume was complete. The temporary slight compression is due to the small compressibility of water. Small holes were bored in the cylinder containing the sample, and when pressure was applied water was driven out of the sample and the volume-change depended upon the quantity of water evacuated. On relief of pressure a small expansion of the clay took place.

The equilibrium-conditions in the aquifers and in the clay-bodies can be illustrated by imagining that Terzaghi's perforated cylinder is placed in a larger cylinder filled with water and that sand-layers are interstratified with clay and the perforations are opposite the sand-layers. The water-pressure in the sand-layers is controlled by the water-level in the outer cylinder, and if the pressure of the water-column, and hence in the sand-layers, is maintained, the buoyant force of the pressure water in the sand prevents escape of water in the clay and compaction of the clay by the weight of the overlying material.

If the water-level in the outer cylinder is lowered, the pressure in the sand-layers is reduced in direct proportion to the lowering of the water-level and this pressure-difference allows the water in the clay to drain into the sand-layers and the clay-compaction is measured by the volume of water driven out of the clay into the sand.

If the water-level in the outer cylinder and hence the water-pressure in the sand-layers is now increased (representing recovery of water-levels in wells), drainage of clays is reduced and later stopped. If the original water-level in the cylinder is maintained, the resulting pressure in the aquifers may force water back into the clay, causing it to expand.

Whether or not volume-recovery is complete, partial, or nil depends largely on whether the structure and mineralogic composition of the clay has been changed by compaction. We know that the change of clay into shale by compaction due to geologic processes is irreversible.

Further measurements of ground-level compared with recovery of water-level should show whether this action in the non-indurated alluvial deposits of the Santa Clara Valley is partially or completely reversible; in other words, whether with complete recovery of water-level in wells the ground-surface level will rise to the original position or to some intermediate level.

Reduction of pressure in the aquifers is due not only to the general lowering of water-level due to over-pumping (static level) but also to pressure-relief during pumping (pumping level). The latter is especially affected by heavy municipal pumping in San José and heavy continuous pumping near Sunnyvale.

Land sinking is also more pronounced in the vicinity of deep wells which tap a larger number of aquifers and which drain a greater thickness of clay than shallower wells.

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DISCUSSION

HYDE FORBES (Consulting Engineer and Geologist, San Francisco, California)--The writer has been receiving the results of the Coast and Geodetic Survey determinations of settlement over the south Bay region. He plotted lines of equal settlement from these data, similar to those presented by Professor Tolman, giving a zone of considerable settlement over the area between Alviso and Milpitas covered by the Coyote Creek fan, and a somewhat greater settlement centered under the building area of San José. That particular distribution is accounted for by the writer in the following reasoning.

Granular and flaky material laid down in or by water entraps a portion of the water in which it was submerged or which laid it down. This intergranular water occurs as particles capable of holding the grains apart and transmitting pressure and as films encompassing soil-particles acting as a lubricant when the particles are forced to slide over each other in coming to firmer bearing under load.

A well was drilled in 1915 on the Standish Ranch near the channel of Coyote Creek between Alviso and Milpitas. It penetrated a thickness of blue clay under the top alluvium and when the underlying sand and gravel was reached a "gusher" resulted. It was estimated that the water-pressure at the top of the casing was in excess of 30 pounds. The flow decreased and the water-level dropped in the casing as pumping in the area of the Coyote Creek fan below the lower gorge lowered the water-table. With the building up of ground-water levels, the well flowed slightly in November 1938, the first flow since 1920.

It is known that the aquifers underlying the lower portion of the Coyote Creek fan have not been dewatered, but the hydrostatic uplift which formerly was a factor in the elevation of the ground-surface was no longer exerted, allowing settlement. That this uplift is substantial was demonstrated in the case of cyclic-load-bearing tests made by the writer and his associates at the McClymonds High School in Oakland. That location is in close proximity to the original (1868) shore-line of the bay and underlaid by a thickness of clay which, in turn, blankets alluvial materials. The tidal loading of that clay-body compressed the water in the underlying material which transmitted the pressure to the test-site. Halts in the compressive settlement-rate were noted to correspond to tidal fluctuations with the test-bearing plate load being built up to six tons over a period of 216 hours.

The deposits lying below the water-table under the city of San José had become adjusted to the water-content and the overburden with its superimposed building load. The aquifers were dewatered through pump-draft and the soil-mat was overstressed with resultant settlement. This settlement would continue so long as more and more material was dewatered. [See comment by authors on page 93.]

AN ELECTRICAL RESISTIVITY-APPARATUS FOR TESTING WELL-WATERS

J. F. Poland and R. B. Morrison

Introduction

A precise but easily operated apparatus for testing resistivity of well-waters has been developed in the Stanford University Hydrologic Laboratory. With it, field-investigations were made on 20 wells in an area contiguous to the southern part of San Francisco Bay where salt-water encroachment into the upper gravels has locally contaminated ground-water supplies.

The apparatus consists of a measuring unit operating on 120- or 240-volt, 60-cycle alternating-current, or from a 6-volt storage-battery, and a cable-unit witn attached electrode-cell. The electrode-cell was lowered into wells and resistivity-measurements were made continuously or at desired depths. Both static and pumping tests were made on wells where possible.

Resistivities of 200 well-water samples, plotted against their chloride-concentrations, yield a curve which shows dispersion into a fairly wide band for waters containing less than 1,000 parts chlorides per million, due to variability in the proportions of the electrolytes they contain. Results of four field-tests are plotted graphically and show the value of the apparatus for location and quantitative measurement of contamination.

Types of circulation in contaminated wells under static and pumping conditions depend on difference in head, difference in density, and relative position of salt-water and fresh-water aquifers. In many cases, both non-pumping and pumping tests are necessary before the exact details of contamination can be obtained.

During the past year work in the laboratory and field has been carried on in the Stanford University Hydrologic Laboratory in order to perfect a precise but easily operated apparatus for the electrical measurement of salinities of well-waters. The instrument developed marks an advance in accuracy and simplicity over equipment used for making similar measurements in the past.

The electrical testing of well-waters is based upon measurement of either conductivity or resistivity. Although pure water is a good dielectric, the conductivity of water increases with increase in dissolved electrolytes. A quantitative determination of the salinity at any desired depth inside a well is made by measuring an electric current passing between two electrodes lowered into the well by a cable and submerged in the water. Sodium chloride is generally the predominant electrolyte in saline-contaminated waters; therefore, increase in conductivity or decrease in resistivity usually indicates an increase in the chloride-ion concentration.

Sampling at various depths below the water-level in a well is necessary for determining either horizons at which salt water is entering the casing or electrolytic differences in the waters from various aquifers tapped by the well. The present apparatus makes such sampling both convenient and rapid, and mechanical collection of samples is eliminated. It is especially adapted for sampling pumping-wells, because the electrode-cell is slim enough to slip through small openings, such as between the casing and the pump-bowls. It is not intended to replace the silver-nitrate titration-method for testing salinity of individual water-samples, for the titration-method is as convenient and is more accurate.

The idea of testing natural waters for the presence of dissolved electrolytes by electrical resistivity-methods is not new. As early as 1897 resistivity-methods of determining soluble salts in soils were described [see 15 of "References" at end of paper]. Earth-resistivity measurements are used extensively for electrical logging of drill-holes in oil-fields [9], and are the basis for several methods of ground-water investigation. The United States Coast Guard uses resistivity-measurements for determining salinity of sea-water [14], and the United States Geological Survey has recently used equipment similar in principle to that described in this article to study salt-water contamination of wells in Texas, Florida, and Iowa [5, 6, 8].

The present investigation was made in an area contiguous to the southern part of San Francisco Bay. Here encroachment of saline waters from the bay into many of the upper gravel-horizons has locally contaminated the ground-water to such an extent that it is unfit for either domestic or irrigation use. Resistivity-tests were run on over 200 samples of natural well-waters, and on nearly 50 samples of artificially diluted saline waters. For each of these samples a chloride-analysis was made, using the silver-nitrate titration-method. Field-tests were made with the resistivity-apparatus on approximately 20 contaminated wells. E. C. Taber assisted with these tests and ran many of the chloride-analyses.

The writers wish to express their appreciation to Professor C. F. Tolman and to Dr. O. E. Meinzer for reading and criticizing the manuscript. They are indebted to Gerhard Fisher of the Fisher Research Laboratories, Palo Alto, California, who designed and assembled the resistivity-measuring unit, and to A. L. Trowbridge, Assistant Comptroller of Stanford University, who made funds available for construction of part of the apparatus. Additional suggestions were made by Professor O. C. Shepard of the Mining Department, and by J. W. McDonnell.

Description of the apparatus

The resistivity-salinity testing outfit consists of a cable-unit and a resistivity-measuring unit. Two cable-units have been developed; a larger unit for deep wells and a smaller unit for wells not more than 500 feet deep. Either may be used interchangeably with the same measuring unit.

The cable-units

Each cable-unit includes a two-wire electric cable of suitable length, a weighted electrode-cell connected to the free end of the cable, and a reel upon which the cable can be wound.

The heavy-duty cable-unit--For the testing cable of the heavy-duty cable-unit, tellurium rubber-covered two-conductor cord was selected. The insulation has the advantages of high tensile strength, resistance to wear and stretching, and high dielectric qualities. No significant electrical-capacity changes occur whether the cable is coiled or uncoiled, dry or immersed in water.

The cable-reel is operated with a hand-crank and a rope-brake is mounted on the axle (Fig. 1). The measuring-unit connection is plugged into a radio jack at one end of the axle and may remain connected while the reel is rotated. The jack revolves within the plug, which remains stationary at the center of the axle without breaking connection.

The heavy-duty electrode-cell is 4-1/2 inches in length and has an outside diameter of 5/8 inch (Fig. 3). Its brass outer casing is in two pieces; the cell-jacket proper and the perforated electrode protector-cap, which may be unscrewed from the jacket. The jacket covers connections from the cable to the electrodes and holds the electrodes and their bakelite spacer-block. The electrodes are pieces of 0.008-inch platinum foil, mounted so as to have areas of about 10 by 7 mm. Weights may be suspended below the cell from the ring through the fish-tail extremity of the protector-cap.

The miniature-electrode cable-unit--The testing cable of the miniature electrode-unit is two-conductor rubber-covered cord 5/16 inch in diameter. It is coiled on a small reel fitted with a hand crank and mounted in a box (Fig. 2). Connection into the measuring unit is made by plugging into a jack socket at one end of the reel-axle.

The miniature electrode-cell is six inches long and 5/16 inch in diameter (Fig. 4). The outer casing is a single piece of 5/16-inch Micarta tubing. The two leads of the testing cable are firmly cemented into the upper end and the 2.5 by 20 mm nickel electrodes are attached along opposite sides of the interior wall. Holes are drilled in the lower part of the tube to insure free circulation of water through the electrode-chamber. The brass fish-tail tube at the bottom of the cell from which weights are suspended may be removed by unscrewing two set-screws and a pipe-cleaner may be inserted into the cell to clean the electrodes.

The smaller cable and electrode-cell are lighter, more portable, less expensive, and able to negotiate very small openings. In the field-tests several wells were encountered where the miniature electrode-cell was able to slip past constrictions between pump-bowls and casing which were too small to permit passage of the larger cell. The electrodes were spaced sufficiently however, to insure proper quantitative differentiation between waters of varying salinities. The electrodes are easily accessible for cleaning, and are mounted so that cleaning and ordinary shocks will not affect their spacing. Provision is made to keep water under high hydrostatic pressure from short-circuiting the electrical connections.

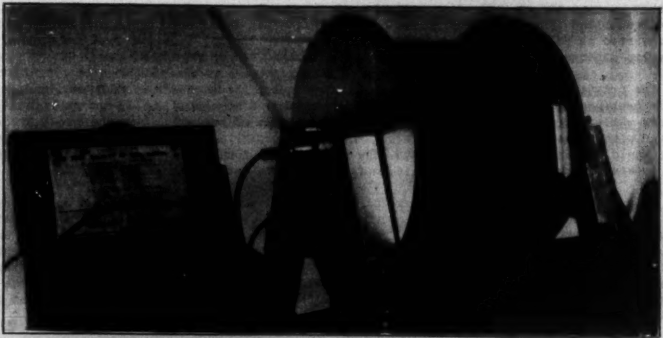


Fig. 1--Measuring unit and heavy-duty cable-unit

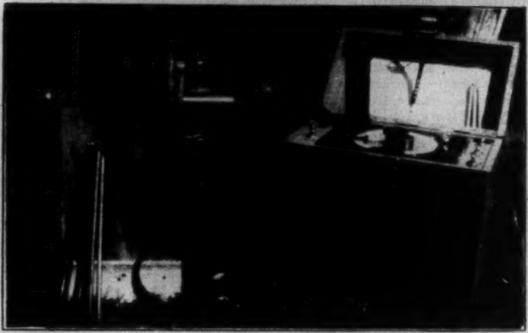


Fig. 2--Miniature electrode-unit and measuring unit

Fig. 3A--Assembled fish-tail

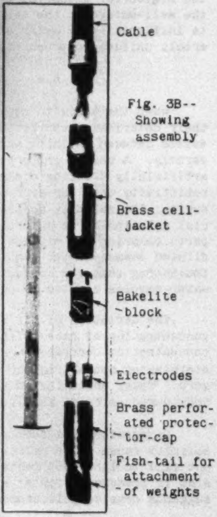

Cable
Brass cell-jacket
Bakelite block
Electrodes
Brass perforated protector-cap
Fish-tail for attachment of weights

Fig. 3B--Showing assembly

Fig. 3--Heavy-duty electrode-cell

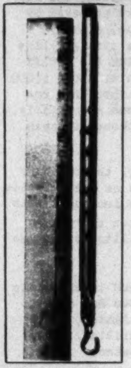


Fig. 4--Miniature electrode-cell

The measuring unit--The electrical-resistivity measuring-unit (Fig. 1) employs an alternating-current resistance-bridge circuit with an unusual but highly sensitive detector--a 6 E 5 electron-ray ("magic eye") tube connected across the output of the bridge. Use of a bridge for resistance-tests provides a high degree of accuracy and independence of reading from line-voltage variations.

The measuring instrument is operated from either a line-voltage of 120 or 240 volts, 60-cycle alternating-current, or 6 volts direct current. When adjusted for 120-volt alternating-current operation the unit may be plugged into an ordinary light-socket. Because in many cases only 240-volt alternating-current is available at electrically equipped pumping-wells, provision is also made for operation on such a current-supply. Either type of alternating current is transformed to 75 volts, passed through the electrode-cell in the bridge-circuit, the bridge-output is transformed to 250 volts alternating current, rectified to direct current, and passed through the electron-ray indicator-tube. For use where suitable current is not otherwise available, the measuring unit may be adjusted to operate on current supplied from an ordinary 6-volt storage-battery. The direct current from the battery is converted to 60-cycle alternating current by a radio vibrator-tube and then transformed to 120 volts alternating current.

The relatively high-voltage electric current passed through the electrode-cell causes appreciable heating of the water within the electrode-chamber if the cell is allowed to remain stationary while taking readings. Although in certain types of resistivity-measurements a lower voltage with corresponding decrease in current and accompanying polarization and heating of fluid would undoubtedly be of advantage, the writers have found the heating-change while the cell is stationary to be a valuable aid in field-tests in water-wells.

Alternating current is necessary to avoid the considerable evolution of gas which would take place at the electrodes if direct current were used and which would interfere with obtaining precise resistivity-measurements. The frequency is not high enough to inhibit all polarization, but the slight evolution of gas which does occur causes no trouble. As an experiment the electrodes were plated with platinum black, which minimized the polarization so that no bubbles of gas were evolved. Field-tests, however, show this to be of no added advantage, for the slight agitation needed to clear the electrode-chamber of water heated by passage of the current also suffices to keep the electrodes free from trapped gas.

Often medium-frequency current (about 1,000 cycles) is employed in making conductivity-determinations, especially in chemical laboratories. A low frequency was adopted for the present apparatus, however, to avoid the excessive capacity-effects which would otherwise be induced in the long testing-cable and which would interfere with resistivity-measurements.

The instrument is calibrated with the testing cable so that only the resistance of the water between the electrodes is measured. For accurate work direct readings of resistivity in ohms are made and the chloride-concentration is found by comparing the indicated resistivity with a salinity-resistivity calibration-graph, such as Figure 5, drawn from data on samples of well-waters from the district. A scale of approximate salinities can be attached to the dial of the instrument for use in rapid reconnaissance-tests.

If the electrolytes in the waters of a new region are chemically different from those of the region for which the measuring unit is calibrated, it should be recalibrated from tests on the well-waters of the new region. As probably 90 per cent of all saline contamination is due to infiltration of water chemically similar to oceanic water and hence the electrolytes are tolerably uniform in proportional composition, this limitation is not important in most cases.

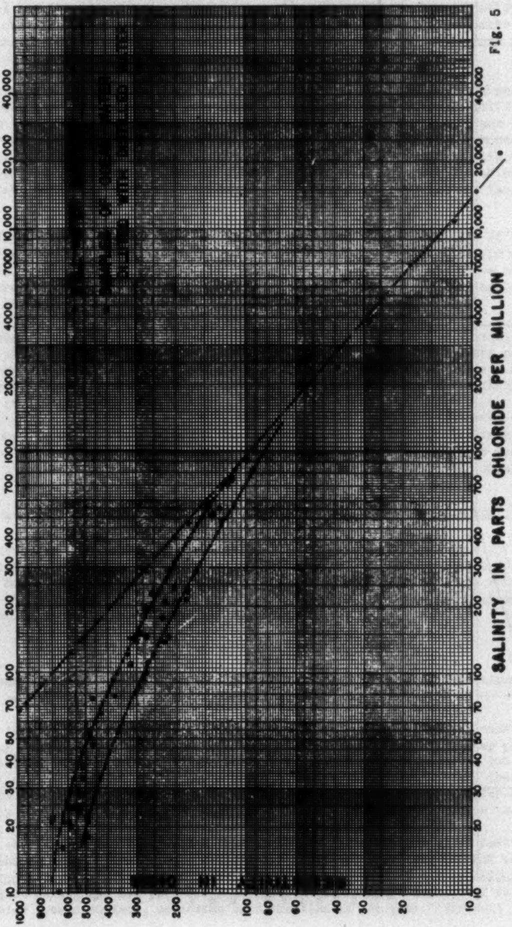
The salinity-resistivity curves

When the specific resistivities of water-samples of varying salinities are plotted against their chloride-concentrations, a hyperbolic curve is obtained (Fig. 5). An inverse relationship exists between salinity and resistivity--as salinity increases, resistivity decreases, and conversely. A nearly proportionate inverse relationship holds for samples which are prepared by artificially diluting oceanic water with varying amounts of distilled water. The salinity-resistivity data for such samples, when plotted using logarithmic scales, form a straight-line curve. The salinity-resistivity curve for well-waters, however, is congruent with the artificial dilution-curve only throughout the high-salinity range. At a concentration of about 1,000 parts chloride per million the well-water curve begins to deviate from that obtained from the diluted oceanic water-samples. For lower salinities the well-water curve flattens appreciably, indicating that the conductivities of the fresher well-waters are greater than those of ocean water-samples diluted to equivalent chloride-content.

The deviation of the well-water curve suggests that, as salinities decrease, the relative concentration of other electrolytes--such as sulphates and carbonates--increases as the chloride-concentration decreases. Furthermore, the relative conductivity of electrolytes increases with diminishing concentration, because dissociation becomes a maximum as concentration approaches zero. Thus, contaminated well-waters with less than 1,000 parts chloride per million cannot be considered as being merely diluted oceanic waters.

Dispersion is a feature characteristic of the well-water curve in the low and intermediate salinity-range. The relatively fresh water-samples collected in the San Francisco Bay area do not fall in line, but instead in a band. Judging from the samples so far investigated, dispersion is pronounced for waters having salinities below 1,000 parts chloride per million. This suggests considerable compositional variability of electrolytes in the fresher waters. Such variability is to be expected, for these waters do not come from a uniform source, such as the ocean, but from a variety of sources.

Sampling and field-tests have proved, however, that the dispersion of the salinity-resistivity curve is not so pronounced as to prevent accurate quantitative salinity-determinations. In the case of an individual well, when samples of variable salt-content are obtained and the resistivities are measured, the resultant points plotted on the salinity-resistivity graph fall along a smooth curve parallel to the band. For this reason, accurate interpretation of individual salinity-curves can be made by collection and chloride-analysis of one or more water-

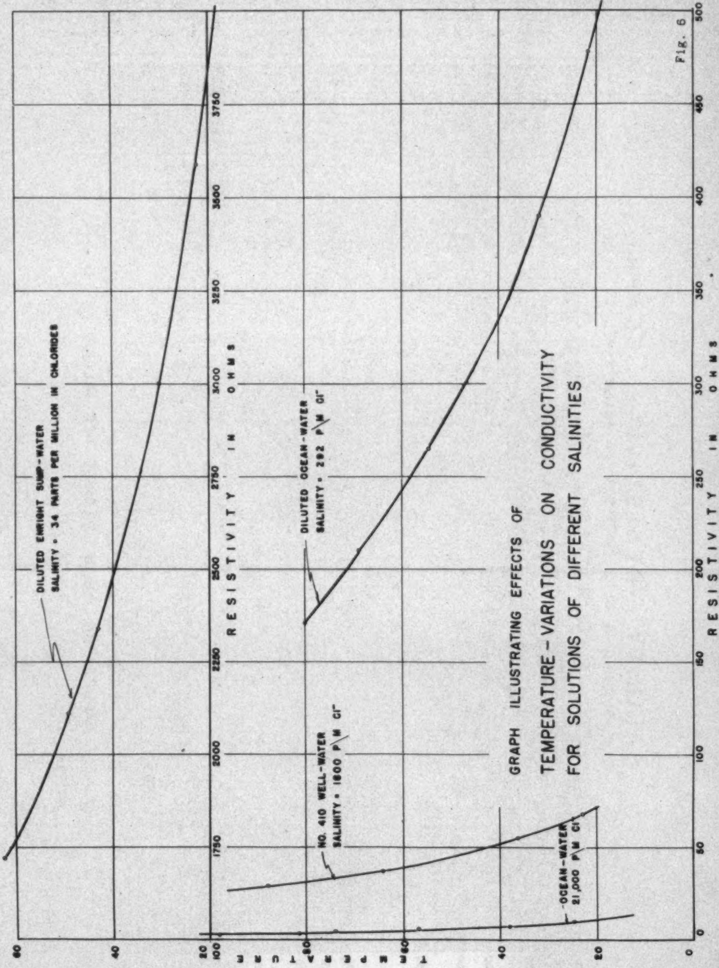


SALINITY - RESISTIVITY GRAPH
SHOWING RESULTS OF TESTS ON WATER-SAMPLES

Fig. 5

samples from the well, plotting of the point on the salinity-resistivity graph and projection of a curve through this point parallel to the dispersion-band.

Effects of temperature-variations on resistivity of saline waters--Owing chiefly to increased ionic velocities, rise in temperature of electrolyte-solutions lowers their resistivity to electric current. This effect becomes more pronounced the more dilute the solutions. For



GRAPH ILLUSTRATING EFFECTS OF
TEMPERATURE - VARIATIONS ON CONDUCTIVITY
FOR SOLUTIONS OF DIFFERENT SALINITIES

Fig. 6

waters of low salinity the temperature-factor becomes an important source of error unless proper corrections are made. Corresponding with the normal thermal gradient of the Earth, well-temperatures increase gradually with depth. Abnormally steep thermal gradients are often encountered in regions of recent or present vulcanism or tectonic activity, and local variations in these gradients are apt to be pronounced.

In order to obtain the highest degree of accuracy in quantitative salinity-testing it is necessary to adopt a standard calibration-temperature, to obtain the temperature of the water being tested, and to correct the resistivity-readings if the temperature of the water differs from the standard. The mean temperature of ground-water at moderate depth in the San Francisco Bay region approximates 20° C and this temperature was adopted as standard. The resistivities of the water-samples plotted on the salinity-resistivity graph (Fig. 5) were all measured at this temperature. In the field-tests when well-waters differed from standard temperature a correction was applied to the readings.

The rate of increase or decrease in resistivity with change in temperature is not constant for all temperature-ranges (Fig. 6). For solutions of equivalent salinity, resistivity-changes will be greater in amount when the temperature-variation occurs at lower temperatures, lesser in amount for higher temperatures. In addition, the rate of resistivity-variation decreases with increase in the chloride-ion concentration of the solutions, and it also varies with changes in electrolytic composition of the water. For practical testing work all these variables cannot be determined; therefore, an exact algebraic statement of the temperature-correction factor is not feasible.

In the ordinary field-tests, for each degree Centigrade that the temperature of the water-sample differed from standard temperature, two per cent of the resistivity-value (in ohms) was added or subtracted, depending upon whether the temperature of the sample was above or below standard temperature. This approximation is reasonably accurate for waters varying between 15° to 25° C and from 20 to 4,000 parts chloride per million.

Heating of water within the electrode-chamber occurs if the electrode-cell is allowed to remain stationary while taking readings. Resistivity-values are obtained which are consistently lower than when the cell is agitated to flush the electrode-chamber with new water. When the cell is stationary heating decreases the resistivity of the water and more than offsets the increase due to gas from polarization.

This feature can be used to determine if the electrode-cell is hanging free in a well. If the cell is hanging free, a sharp change in resistivity will occur if the cable is gently jerked up and down after being allowed to remain stationary for a minute. If no change occurs, the cell is hung up.

Field-tests on some typical wells

In order to determine the value and application of the resistivity-apparatus for locating the source of saline-contaminating waters in wells, field-tests were made on about 20 contaminated wells. In most cases the wells tested were contaminated by water from San Francisco Bay, which varies from 10,000 to 15,000 parts chloride per million. Uncontaminated well-waters in the area range from 10 to 60 parts chloride per million.

Results of resistivity-tests on some typical wells

The data presented for each of the following four wells are typical of conditions which may be encountered in making resistivity-tests on contaminated wells.

Well A--This is an abandoned well 45 feet deep with an open casing. It is located near a slough close to San Francisco Bay and is subject to contamination during high-water periods. The resistivity-test on this well (Fig. 7) indicates that salinity increases from 900 parts chloride per million at the top to 11,000 parts per million at the bottom. Rapid increase in salinity with depth is common in unpumped wells contaminated by salt water. A water-sample collected near the top would give a misleading test of the amount of contamination in the well.

Well B--This well is located 1-1/2 miles from the bay at an elevation of 35 feet. Water-bearing gravels occur between 219-235 feet, 249-257 feet, 269-285 feet, and 290-312 feet; the casing is perforated opposite each of these gravel-strata. There is also a thin 3-foot gravel at 192-195 feet, but the casing was not perforated at this level. Static water-level varies between 80 and 115 feet below ground-surface, depending upon the time of the year. The well is equipped

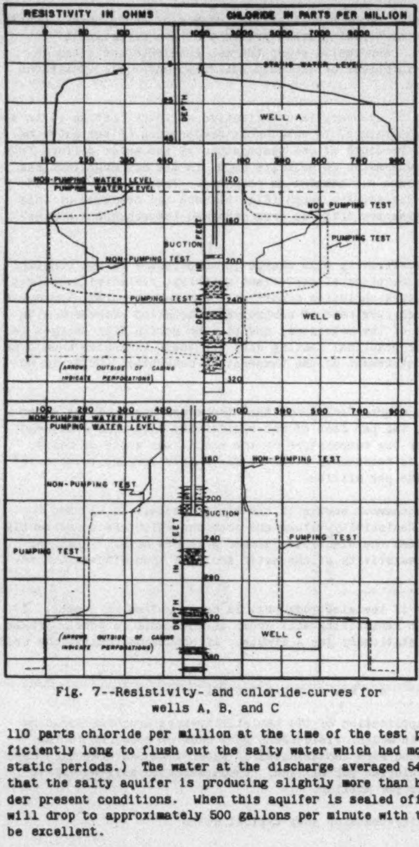


Fig. 7--Resistivity- and chloride-curves for wells A, B, and C

with a deep-well turbine-pump with top of bowls at 156 feet and bottom of suction at 184 feet.

A resistivity-test was made after the pump had been shut down for two hours (non-pumping test). A second test (pumping test) was made a few minutes later while the well was producing 1,000 gallons per minute with 15 feet draw-down from a static level of 115 feet (Fig. 7). The non-pumping test showed a rapid increase in salinity between 220 and 230 feet, with constant salinity from 230 feet to the present bottom of the well at 300 feet. After completion of the non-pumping test the electrode-cell was hung at 295 feet and the pump was started. The horizontal dashed line shows the change in resistivity and in salinity which occurred during the ten minutes after starting the pump. The quality of the water rising through the casing at 295 feet changed from 920 to 30 parts chloride per million.

After the well had been pumped for 25 minutes the electrode-unit was slowly raised to the surface and the pumping curve was obtained. This curve shows a sharp increase in salinity between 235 and 200 feet, with a mixture at the suction-intake containing 540 parts chloride per million.

The two curves show clearly that fresh bottom-water was contaminated by salty water (920 parts chloride per million) entering from the aquifer at 219-235 feet. The water from the lower aquifers contained less than 100 parts chloride per million. (The pumping mixture between 260 and 240 feet showed 110 parts chloride per million at the time of the test probably because the pump had not run sufficiently long to flush out the salty water which had moved into the fresh-water aquifers during static periods.) The water at the discharge averaged 540 parts chloride per million, indicating that the salty aquifer is producing slightly more than half the water delivered by the well under present conditions. When this aquifer is sealed off it can be anticipated that production will drop to approximately 500 gallons per minute with the same draw-down, but the quality will be excellent.

Salt water from the 219-235-foot aquifer filled the 14-inch casing down to 300 feet 40 minutes after the pump was shut off, or moved downward at the rate of two feet (15 gallons) per minute. Evidently the salt water moves into the fresh-water aquifers at this rate during non-pumping periods, but is flushed out through the discharge during pumping.

Well C--This well, 380 feet deep, is located in Atherton, California, approximately 1,000 feet north of the Atherton railroad station. Samples collected from the pump-discharge a few days after completion of the well showed an analysis of 200 parts chloride per million.

The solid line on Figure 7 shows the results of a non-pumping resistivity-test made in order to locate possible sources of contamination. From water-level at 127 feet down to 200 feet the chloride-concentration increased from 100 to 120 parts per million. It rose to 140 parts per million at 210 feet, then remained constant to 314 feet, where the salt-content abruptly rose to 750 parts per million. From 317 feet to bottom at 375 feet the salinity remained constant.

This static test indicated that the salt water was entering below 314 feet.

After this test was made, a deep-well turbine-pump was installed. The well was pumped for several days and then a resistivity-test was made while the well was pumping 166 gallons per minute. Static level was at 120 feet, pumping level at 127 feet, and suction-intake at 212 feet.

During the pumping test the water below 212 feet was rising through the well to the suction-intake and the water from the aquifers above 212 feet was descending to that point. The water at the bottom showed 800 to 900 parts per million chloride, but from 369 feet to 322 feet the salinity remained constant at 760 parts per million. At 322 feet the effect of the fresher waters coming from the adjacent aquifers rapidly decreased the salinity. From 308 feet to the suction-intake, the salinity remained essentially constant at 290 parts per million. As it entered the intake, the water ascending from below mixed with the water descending from above. A sample collected from the discharge during the test contained 188 parts per million, indicating that approximately 50 per cent of the water was coming from below the suction. Thus, about 80 gallons per minute were being produced from the aquifers below 300 feet. Both the pumping and non-pumping graphs showed that the clayey gravel-stratum at 250-263 feet produced no water.

If we assume that the water in the aquifers from 308-317 feet contained 140 parts per million, as the non-pumping test indicates, the relative production from these gravels may be determined from the pumping graph. The decrease from 740 to 290 parts per million indicates that approximately 60 gallons per minute were coming from the two aquifers between 308 and 326 feet, and about 20 gallons per minute from the bottom two aquifers.

Comparison of the pumping and non-pumping graphs shows that under non-pumping conditions the head in the salt-water aquifers was sufficient to force salt water up into the aquifer located between 308 and 317 feet. The non-pumping graph shows that salt water was moving into the bottom foot of the 308-317-foot aquifer while the well was idle.

As a result of this test it was recommended that the well be filled with cement to the 340-foot level. This was done and subsequent tests proved that the contamination had been eliminated.

Hydrologic conditions in contaminated wells

The quantity and direction of circulation in a non-pumping well depend upon conditions operative in the aquifers tapped by the well. These conditions are controlled by: (A) Relative hydrostatic heads in the aquifers; (B) relative permeabilities of the aquifers; (C) relative densities of waters in the aquifers; (D) relative position of saline and fresh-water aquifers; (E) relative thickness of aquifers pierced by the well; (F) diameter of the well; (G) freedom of entry of water into the well, influenced by (1) perforations in casing, size, and number, (2) holes rusted in casing, (3) breaks in outer seal, and (4) leaks in casing around joints and along seams.

Direction of circulation in a non-pumping well is determined by the number and relative positions of the aquifers tapped by the well, and upon the head and density of water in each. If all aquifers pierced by a well have a common head, there will be no circulation of water through the casing unless the dissolved solids vary sufficiently so that the waters differ in density. When a well taps aquifers containing waters of differing densities, slow circulation will take place through the well, but it will always be downward under conditions of common head.

In alluvial fan deposits and in stratified deposits of interbedded sands, clays, and gravels, unequal heads are often encountered in different aquifers pierced by a well. The water-circulation under non-pumping conditions is ordinarily controlled by difference in head rather than by difference in density, because difference in density can only overcome a very low head differential.

Table 1 shows the heights of columns of fresh water (50 parts chloride per million or less) needed to balance 200-foot columns of salt water of varying salinity. It is calculated on the assumption that the specific gravity of sea-water is 1.025 and that contaminating waters in wells are dilutions of sea-water.

Salt water has a higher density than fresh water and therefore will settle in a non-pumping well under conditions of common head in all aquifers.

In a non-pumping well piercing two aquifers circulation may occur in four possible ways,

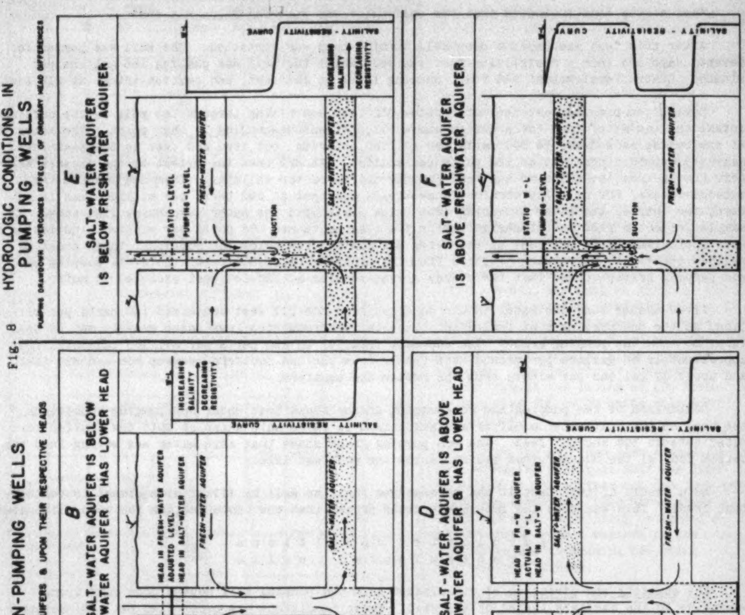


Fig. 8

HYDROLOGIC CONDITIONS IN NON-PUMPING WELLS
DEPEND UPON RELATIVE POSITIONS OF SALT & FRESHWATER AQUIFERS & UPON THEIR RESPECTIVE HEADS
A
SALT-WATER AQUIFER IS BELOW FRESHWATER AQUIFER & HAS HIGHER HEAD
HEAD IN SALT-WATER AQUIFER
ADJUSTED (ACTUAL) WATER-LEVEL
HEAD IN FRESH-WATER AQUIFER
FRESH-WATER AQUIFER
SALT-WATER AQUIFER
INCREASING SALINITY
DECREASING RESISTIVITY
SALINITY - RESISTIVITY CURVE
W-L
B
SALT-WATER AQUIFER IS BELOW FRESHWATER AQUIFER & HAS LOWER HEAD
HEAD IN FRESH-WATER AQUIFER
ADJUSTED LEVEL
HEAD IN SALT-WATER AQUIFER
C
SALT-WATER AQUIFER IS ABOVE FRESHWATER AQUIFER & HAS HIGHER HEAD
HEAD IN SALT-W AQUIFER
ACTUAL W-L
HEAD IN FR-W AQUIFER
D
SALT-WATER AQUIFER IS ABOVE FRESHWATER AQUIFER & HAS LOWER HEAD
HEAD IN FR-W AQUIFER
ACTUAL W-L
HEAD IN SALT-W AQUIFER
HYDROLOGIC CONDITIONS IN PUMPING WELLS
PUMPING DRAWDOWN OVERCOMES EFFECTS OF ORDINARY HEAD DIFFERENCES
E
SALT-WATER AQUIFER IS BELOW FRESHWATER AQUIFER
STATIC-LEVEL
PUMPING-LEVEL
SUCTION
F
SALT-WATER AQUIFER IS ABOVE FRESHWATER AQUIFER
STATIC W-L
PUMPING-LEVEL

depending upon (1) the relative position of fresh- and salt-water aquifers, and (2) the head of water in each. Figure 8 illustrates the four types of circulation, any one of which may occur in a well piercing two aquifers. This circulation may be complicated if a well taps more than two aquifers.

Table 1--Heights of columns of fresh water necessary to balance salt water of different salinity

Salinity of salt-water column, parts chloride per million	Salt-water column, depth in feet	Fresh-water column, depth in feet
250	200	200.062
500	200	200.125
1,000	200	200.25
5,000	200	201.25
10,000	200	202.50
20,000 (oceanic water)	200	205.00

Usually a pumping test is needed to supplement data obtained from a non-pumping test, especially if the well has not been pumped for some time. The non-pumping test is very important, however, for determining whether contamination is continuous during non-pumping periods. If the head in the fresh-water aquifers is greater than that in the contaminating aquifer, fresh-water circulation will be maintained throughout the well under non-pumping conditions (Fig. 8, B and D). When both pumping and non-pumping tests are made and a double graph obtained, no difficulty should be experienced in determining which of the four conditions pictured in Figure 8 exists.

It may be necessary to pump a contaminated well for a considerable length of time before the intruded aquifers are completely flushed out. When this condition has been attained, the resistivity-salinity graph obtained should be identical with any subsequent test made during the same pumping period. The two diagrams in Figure 8 (E and F) show the nature of the pumping circulation after equilibrium has been reached, depending upon the relative position of salt-water and fresh-water aquifers. Any difference in head between aquifers will usually be completely overshadowed by the draw-down. However, any large-head differential under static conditions will be reflected in the amount of pumping time necessary before the equilibrium-curve is obtained.

The electrical-salinity log of Well B (Fig. 7) under non-pumping conditions exemplifies the conditions shown in diagram C of Figure 8. Here the salt-water aquifer is feeding water into the underlying fresh-water aquifer. The salinity log for Well C (Fig. 7) shows a case which follows the conditions illustrated in diagram A of Figure 8--where the salt-water aquifer is under higher head and feeds water into an overlying fresh-water aquifer.

The aquifers contaminated by salt water from San Francisco Bay normally overlie the fresh-water aquifers (the top 100 feet is contaminated) and the non-pumping circulation is downward. This condition lends itself to rapid contamination of all aquifers when wells are drilled to various depths and act as pipes to conduct salty water downward from one aquifer to another. This feature is particularly unfortunate if the guilty wells are only pumped a small part of the time and are allowed to act as avenues of contamination in the non-pumping periods. For example, the downward leakage of salt water in Well B was only 15 gallons per minute, yet over a period of one year, if the well was never pumped, approximately 23 acre-feet of salt water would be fed into the fresh-water aquifers. If we assume an effective porosity of 20 per cent, this water would fill a volume of 115 acre-feet of aquifer. Such a condition actually exists in many abandoned and some slightly pumped wells in this area. Cognizant of this condition, the County of Santa Clara recently instituted a careful well-sampling project to determine areas and conditions of contamination, as a preliminary to corrective measures designed to prevent such useless spoilage of valuable ground-water resources in the future.

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DISCUSSION

HYDE FORBES (Consulting Engineer and Geologist, San Francisco, California)--In connection with the results of testing of well-waters for chloride-content Mr. Poland presented curves of resistivity plotted against chloride-content with the points varying over 100 per cent in chloride for the same resistivity. That was found to be so in the deep wells of the California-Hawaiian Sugar Company near Napa. The sugar-refining process is affected detrimentally by small percentages of chloride. Efforts were made to make quantitative determinations of the chloride-content of the well-waters electrolytically through an apparatus similar to that developed by Mr. Poland. It was found necessary to take two or more samples by means of a thief at points in the well-column (wells 1,100 to 1,600 feet deep) and the chemical analysis of those samples had to be correlated to conductivity before the electrolytic traverse of the individual well could be given a satisfactory quantitative interpretation. And that relation only existed for that well at that time.

GEOCHEMICAL PATTERNS IN COACHELLA VALLEY

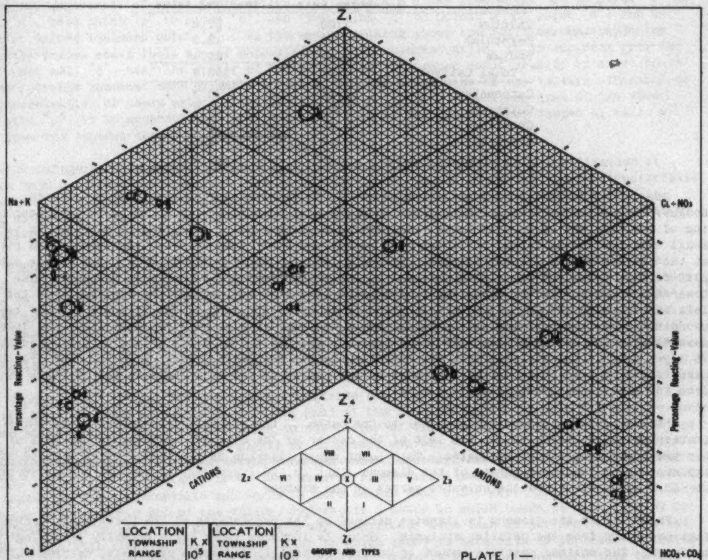
Raymond A. Hill

Tens of thousands of samples of water have been taken from streams, springs, and wells for chemical analysis, without much use having been made of the results. Unfortunately, the chemists have been little concerned with any engineering interpretation of such analyses and the engineers have had no ready method of interpreting them. Consequently, engineers and agriculturists have usually limited themselves to consideration of only the total dissolved solids, or the total hardness, or possibly the amount of chlorides; the real significance of the analyses has been overlooked.

This almost universal failure to make full use of chemical analyses of stream and ground-waters has been unnecessary because the way was pointed out by Chase Palmer many years ago [U.S. Geol. Sur. Bull. 479] and the method was subsequently developed by F. W. Clark [U.S. Geol. Sur. Bull. 695]. The writer, faced with the problem of interpreting several thousand analyses of water from the Salt River Valley in Arizona, developed a chart, patterned after Palmer's work, which permits of graphic representation of the chemical characteristics of different natural waters and of mixtures of those waters.

Basically this geochemical chart consists of four equilateral triangles, designed for tri-linear plotting, and arranged in the form shown in Plate 1. At the lower left is a triangle for plotting the percentage reacting-values of the cations commonly found in surface and groundwaters. The triangle at the lower right is similarly designed for plotting the percentage reacting-values of the principal anions. The triangle fórming the left half of the diamond is designed for plotting the geochemical groups which are present when the sodium percentage exceeds the chloride percentage. The triangle at the right center is similarly used for plotting the geochemical groups when the percentage of sodium is less than the percentage of chlorides.

In his work, Palmer grouped the strong acids together and arrived at four principal geochemical classifications: Primary salinity; primary alkalinity; secondary salinity; and secondary alkalinity. For engineering and agricultural use, it seemed advisable to modify Palmer's grouping and to use the following geochemical classifications:



LOCATION TOWNSHIP RANGE SECTION	K x 10⁵	LOCATION TOWNSHIP RANGE SECTION	K x 10⁵
a 4-6-28	33	e 5-7-30	49
b 3-5-17	129	f 6-7-1	29
c 5-7-12	108	g 7-8-16	24
d 5-6-20	127	h 8 9 33	372

PLATE I — GEOCHEMICAL CLASSIFICATION OF WATERS FROM WELLS IN COACHELLA VALLEY CALIFORNIA

Group Z1--The Common Salt Group, including sodium chloride, potassium chloride, sodium nitrate, and potassium nitrate

Group Z2--The Alkali Group, including sodium sulphate, sodium bicarbonate or carbonate, potassium sulphate, and potassium bicarbonate or carbonate

Group Z3--The Bittern Group, including calcium chloride, magnesium chloride, calcium nitrate, and magnesium nitrate

Group Z4--The Hardness Group, including calcium bicarbonate or carbonate, magnesium bicarbonate or carbonate, calcium sulphate, and magnesium sulphate.

Data from almost any valley in the Southwest could be used for illustration of this method of classification, but Coachella Valley in southern California has been selected because waters of widely different characteristics are found there. The eight points on Plate 1 show the characteristics and relative concentration of salts in the water from typical wells in the valley. Well "a" is in the center of the valley northwest of Indio; wells "b" and "c" are along the fault-system on the northeast side of the valley; well "d" is near the southerly edge of the valley west of Indio; well "e" is just west of Indio; well "f" is south of Indio in the center of the valley; well "g" is south of Thermal; and well "h" is along the fault west of Salton Sea. These analyses were selected from more than one hundred, furnished by courtesy of M. R. Huberty and V. P. Sokoloff, Agricultural Experiment Station, University of California, and are generally characteristic of the different classes of water found along the sides and in the center of Coachella Valley from Palm Springs to Salton Sea. To illustrate the method of plotting on the geochemical chart, the analysis of water from well "a", in Sec. 28, T. 4 S., R. 6 E., is given in Table 1.

Table 1--Chemical analysis of water from well "a"

Ions	Milligram-equivalents	Percentage reacting-value
Calcium	1.90	57.6
Magnesium	0.44	13.3
Sodium	0.96	29.1
Total Cations	3.30	100.0
Carbonates	2.44	76.3
Sulphates	0.41	12.8
Chlorides	0.31	9.7
Nitrates	0.04	1.2
Total Anions	3.20	100.0

Due to the limitations of trilinear plotting, it is necessary to group potassium with sodium, carbonates with bicarbonates, and nitrates with chlorides. In a few cases this combining of two ions may cause difficulty, but generally the amount of potassium or nitrates is very small relative to the total. If there were no cations other than calcium, the point would plot at the calcium vertex of the triangle. Actually, calcium constituted 57.6 per cent of the sample, so that point "a" plots 57.6 per cent of the perpendicular distance from the upper base towards the calcium vertex. Similarly, the point lies 13.3 per cent of the distance from the left-hand base to the magnesium vertex, which is at the right-hand of the triangle. These two coordinates fix the position of the point, which necessarily lies 29.1 per cent above the lower base towards the sodium vertex. In like manner, point "a" in the anion triangle is plotted at 76.3 per cent of the distance from the base towards the carbonate vertex, 12.8 per cent from the base towards the sulphate vertex, which is at the center of the main diagram, and 10.9 per cent from the base towards the chloride vertex.

Projection of these points parallel to the bases of the respective triangles to an intersection gives the point "a" on the left of the center of the diamond, that is, in the left of the two upper equilateral triangles. This point could likewise be plotted by using oblique coordinates from the lower vertex of the diamond--that is, 29.1 per cent toward the sodium vertex and 10.9 per cent toward the chloride vertex of the diamond.

Point "a" in the diamond is likewise defined by the percentages of the geochemical groups that are found from the detailed analysis. Group Z4 includes those salts normally producing hardness. The maximum possible amount of calcium carbonate, magnesium carbonate, calcium sulphate, or magnesium sulphate that might be precipitated from solution is limited by the amount of calcium and magnesium present in this sample--that is, 70.9 per cent of the total. Conversely, the greatest amount of sodium chloride, potassium chloride, sodium nitrate, or potassium nitrate, which might remain in solution after other salts were precipitated, is limited by the amount of chlorides and nitrates present--that is, 10.9 per cent. The remaining sulphates and carbonates and the remaining sodium and potassium amount to 18.2 per cent of the total. In the water from well "a" there is thus found 10.9 per cent of Group Z1, the common salt group; 18.2 per cent of Group Z2, the alkali group; none of Group Z3; and 70.9 per cent of Group Z4, the hardness group. Point "a", therefore, lies 18.2 per cent of the distance from the center line of the diamond to the Z2-vertex at the left, 10.9 per cent from the side opposite the Z1-vertex towards that vertex, and 70.9 per cent from the opposite base toward the Z4-vertex.

One of the characteristics of this system of plotting analyses is that any mixture of two waters must lie on the line connecting the plotted positions of the individual samples comprising the mixture. If two waters of equal concentration are mixed in equal amounts, the point for the mixture will fall midway between the plotted positions for the separate waters, but if one water has twice the concentration of the other, the plotted position will be one-third of the distance from the stronger water. In other words, the mixture plots at the center of gravity when the points for the respective waters are given the weight due them because of the concentration of salts and volume of water going to make up the mixture. In a similar manner, the position for a mixture of three or more waters can be determined. This is done most readily by use of equivalent weights, such as ton-equivalents. Equivalent weights are obtained by summating, for the entire volume of water, the total weight of each ion divided by its corresponding combining weight.

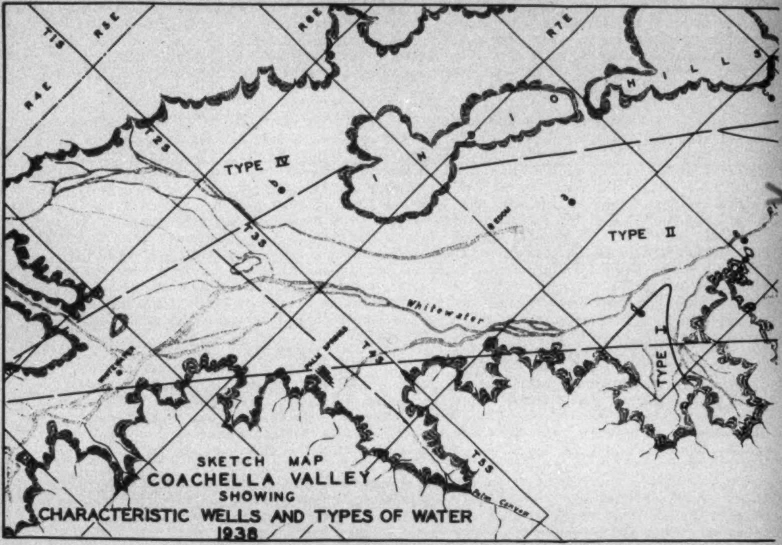
Point "e" in Plate 1 is characteristic of the results of mixing waters of widely different characteristics. The water flowing down the main trough of Coachella Valley apparently is similar to sample "a". With this is mixed, however, water originating along the main fault-system northeast of the valley, such as that found in well "b" near the upper end and in well "c" directly north of Indio. The water in well "e" is likewise influenced by waters of a markedly different character entering from the southwest, presumably rising along another fault-system. Point "d" is characteristic of these fault-waters. If lines are drawn from point "a" to point "b" or point "c", from point "a" to point "d", and from point "d" to point "b" or point "c", the triangle so formed includes point "e". As the waters arising along the fault-systems bordering Coachella Valley above Indio are of approximately equal concentration, it is apparent from the chart that well "e", near the center of the valley, is influenced about equally by those fault-waters; perhaps somewhat more by water entering from the south side of the valley. Inasmuch as the concentration of these waters from the fault-zones is about four times that of the water from well "a", it is apparent also that more than half of the ground-water tapped by well "e" came down the central trough of the valley.

The foregoing discussion illustrates the method used for geochemical classification of waters from wells and other sources. In the accompanying Plates, there are shown characteristic variations in the waters of Coachella Valley, together with the apparent position of faults along which water rises in sufficient volume to supplant largely the ground-water supply fed by surface-streams draining the San Bernardino and San Jacinto Mountains.

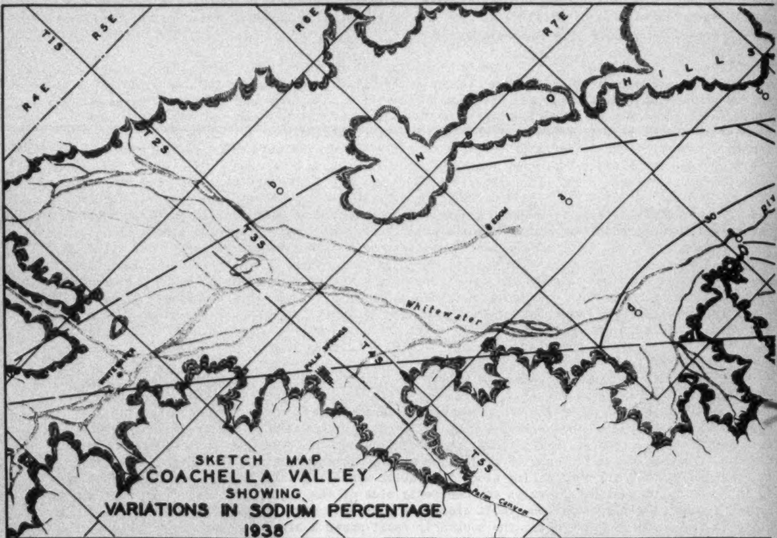
Plate 2 shows the location of the wells from which the samples plotted on Plate 1 were taken. The water from each of these wells was generally characteristic of the water from other wells in the same part of the valley. In Plate 2 are shown also the zones within which the waters of various types are found, usually to the exclusion of waters of other types. These type numbers are arbitrary and represent merely subdivisions of the diamond as shown in the small figure at the bottom of Plate 1. The use of these types has been found to be convenient, particularly in cataloging ground-waters.

Types I, III, V, and VII are used to subdivide the right half of the diamond; Types II, IV, VI, and VIII are used to subdivide the left half of the diamond; Type X is used to describe those waters whose plotted positions are close to the center of the diamond. Most surface-waters and ground-waters contain salts of the alkali or Z2-group, and the odd-numbered types are usually found only where there is contamination from sea-water, drainage-water, or water rising along faults. Type II is characteristic of most natural river-waters and ground-water in that calcium and magnesium salts predominate and there is more sodium than chlorides. Type VI, which occurs near the southeasterly end of the valley, represents a water in which there is more than 50 per cent sodium and in which the alkali or Z2-group constitutes more than 50 per cent of the total salts. Type VIII likewise represents a water in which there is more than 50 per cent of sodium but in which the predominant salt is sodium chloride. Type IV also contains more than 50 per cent of sodium but less than 50 per cent of any one of the geochemical groups. Type I, which occurs at a few places in Coachella Valley, includes all waters, in which there is less than 50 per cent sodium and less than 50 per cent of chlorides and nitrates, but in which there are more chlorides and nitrates than sodium so that some salts of the Z3-group are present. Type VII is found in the valley only near Salton Sea; this type includes all waters in which more than half of the salts fall in group Z1 and in which there are some salts in group Z3. Oceanic water and many drain waters are of this type.

The variation in sodium-content of waters in Coachella Valley, expressed in percentage of total cations, is shown in Plate 3. In the upper end of the valley the sodium percentage is consistently less than 30; below Indio the sodium percentage increases rapidly, particularly towards the east side of the valley, and below Thermal there are practically no ground-waters that contain 20 per cent of salts other than sodium salts. Part of the increase in sodium percentage is probably due to reuse of irrigation-water, but apparently this effect is secondary to the influence of waters originating along the faults bordering this valley. In this connection, it is to be noted that the fault on the northerly side of the valley produces water having a higher sodium percentage than the fault along the southerly side, excepting where the latter is close to Salton Sea. Conversely, the southerly fault shows a higher proportion of chlorides


T1S
R5E
R6E
R7E
R4E
T2S
T3S
T4S
T5S
INDIO HILLS
TYPE IV
TYPE II
TYPE I
Whitewater
Palm Springs
Palm Canyon

SKETCH MAP
COACHELLA VALLEY
SHOWING
CHARACTERISTIC WELLS AND TYPES OF WATER
1938


T1S
R5E
R6E
R7E
R4E
T2S
T3S
T4S
T5S
INDIO HILLS
Whitewater
Palm Springs
Palm Canyon

SKETCH MAP
COACHELLA VALLEY
SHOWING
VARIATIONS IN SODIUM PERCENTAGE
1938

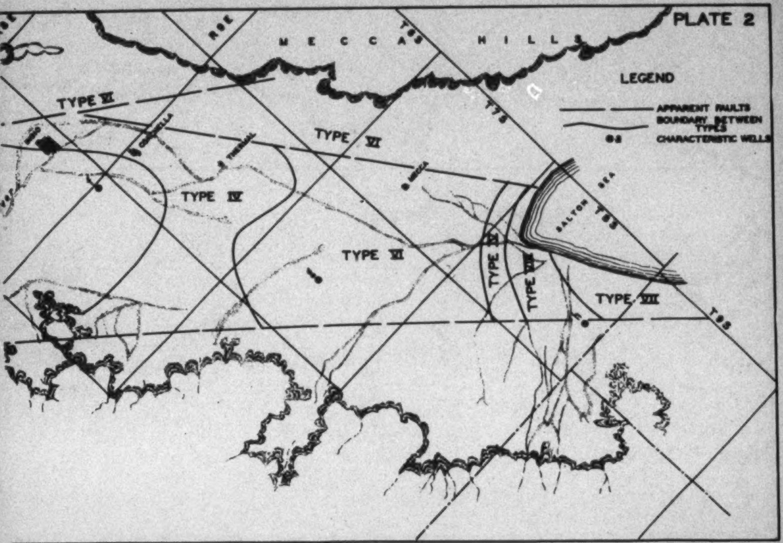


PLATE 2

R6E
R8E
T6S
T7S
T8S
T9S
MECCA HILLS
LEGEND
APPARENT FAULTS
BOUNDARY BETWEEN TYPES
CHARACTERISTIC WELLS
INDIO
COACHELLA
THERMAL
MECCA
SALTON SEA
TYPE VI
TYPE VI
TYPE IV
TYPE VI
TYPE VI
TYPE VIII
TYPE VII

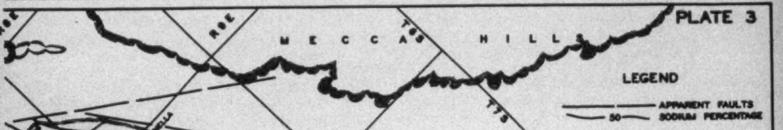
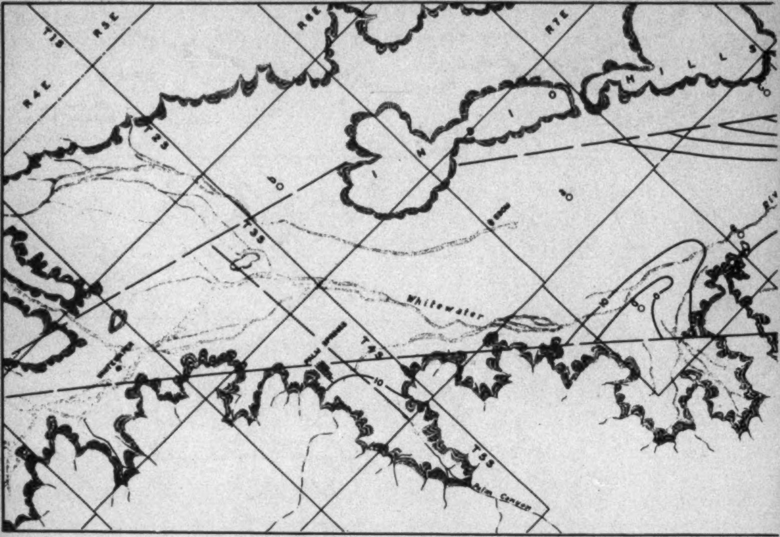


PLATE 3

R6E
R8E
T6S
T7S
T8S
T9S
MECCA HILLS
LEGEND
APPARENT FAULTS
50 SODIUM PERCENTAGE
COACHELLA
THERMAL
MECCA
SALTON SEA
50
50
60
70
80
80



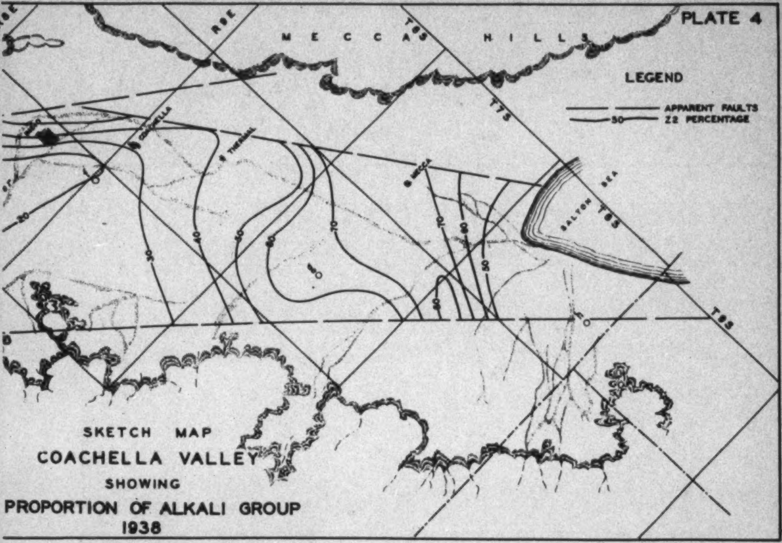
than is found either in the center of the valley or along the fault on the opposite side.

The variation in the percentage of group Z2--the alkali group--is likewise indicative of the origin and direction of movement of ground-waters in Coachella Valley. The relative amount of salts included in group Z2 is shown in Plate 4. In the upper end of the valley there is generally less than 20 per cent of the alkali group present in the ground-waters, except along the northeasterly fringe where waters rise along faults. On the opposite side of the valley, however, there are areas in which the ground-waters show less than ten per cent of group Z2, and in some cases none at all. South of Indio the proportion of the Z2-group increases rapidly, particularly near the northeasterly side of the valley, due undoubtedly to the infiltration of water of Type VI originating along this fault-zone. On the south side of the valley, just opposite the head of Salton Sea, the Z2-group increases to a maximum of more than 80 per cent of the total salts contained in the well-waters. Farther to the southeast, however, the proportion of the alkali or Z2-group decreases rapidly relative to the common salt or Z1-group, due probably to the influence of Salton Sea upon the ground-waters near it.

The lines separating the various types and the contours of equal percentage concentration shown in Plates 2, 3, and 4 are necessarily generalized. There are several wells within Coachella Valley whose waters do not correspond to these general characteristics, but where the departures were appreciable it was found that the wells were either very deep or very shallow.

In general, it is apparent that Whitewater River and other streams draining the easterly slopes of San Bernardino and San Jacinto Mountains contribute primarily to the water in the trough of Coachella Valley above Indio. Even in the upper portion of the valley, however, the ground-waters along each side are strongly influenced by water rising along fault-zones. Below Indio, the contribution through absorption from surface-streams appears to be secondary to contributions from water arising along the fault-zones which border the valley. Ground-waters flowing down the valley apparently are forced to the north by a barrier west of Indio and thereafter are found only in a narrow strip. About ten miles southeast of Indio the ground-water moving down the trough of the valley loses its identity, and waters from the fault-systems bordering the valley predominate. Farther south these waters are in turn mixed with others more characteristic of the Salton Sea.

PLATE 4



SKETCH MAP
COACHELLA VALLEY
SHOWING
PROPORTION OF ALKALI GROUP
1938

This description of the ground-waters of Coachella Valley has been given primarily as an illustration of the method of geochemical classification that was developed as a tool for engineers and others who are not chemists. Much more intensive study of the ground-water hydrology of Coachella Valley should be undertaken, because many of the wells now tap supplies that are undesirable for agricultural use, and because works are now under construction for the delivery to Coachella Valley of Colorado River water, which differs markedly from most of the waters now found there.

Leeds, Hill, Barnard and Jewett,
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Los Angeles, California

INTERPRETATION OF GROUND-WATER ELEVATION MEASUREMENTS

C. N. Johnston and M. R. Huberty

Though the title of this paper permits a rather general discussion of water-table problems, the authors intend to review the literature briefly and to give some of their findings in a field-study of a section of the Sacramento Valley. Besides the abundant data presented in Water-Supply Papers of the United States Geological Survey, many independent reports and papers bear upon ground-water tables. Selected highlights from a few of these publications will bring the present discussion into focus.

Lee [see 5 of "References" at end of paper], working in Owens Valley, found by using 10-foot-deep "post-hole" wells dug in clay that "ridges" followed the beds of streams and that "mounds" extended below irrigated fields, whereas the water-table contours roughly followed the general valley-contours. Meinzer [6] made a water-table contour-map of Silverbow Basin, Montana, by using data from wells ranging from 12 to 119 feet in depth, with water-levels from two to 89 feet below the surface. Clark [1, 2], studying the Niles Cone and Morgan Hill areas in California and using numerous wells whose water-levels varied during each season, drew conclusions as to specific yields of the areas. In the Morgan Hill region he checked the specific-yield data by pump tests. White [9], working in Escolante Valley in Utah, dug four pits to the water-

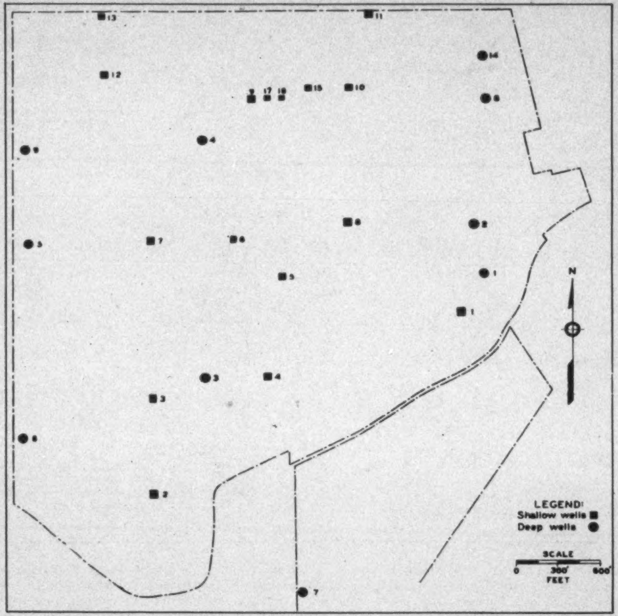

13
11
14
12
9
17
18
15
10
6
4
9
8
2
5
7
6
5
1
1
N
3
4
3
8
2
LEGEND:
Shallow wells ■
Deep wells ●
SCALE
0
300
600
FEET
7

Fig. 1--Location of observation-wells at the University Farm, Davis, California

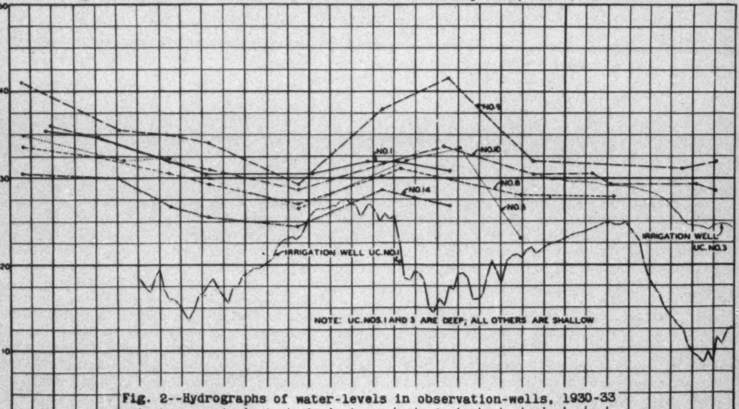


Fig. 2--Hydrographs of water-levels in observation-wells, 1930-33

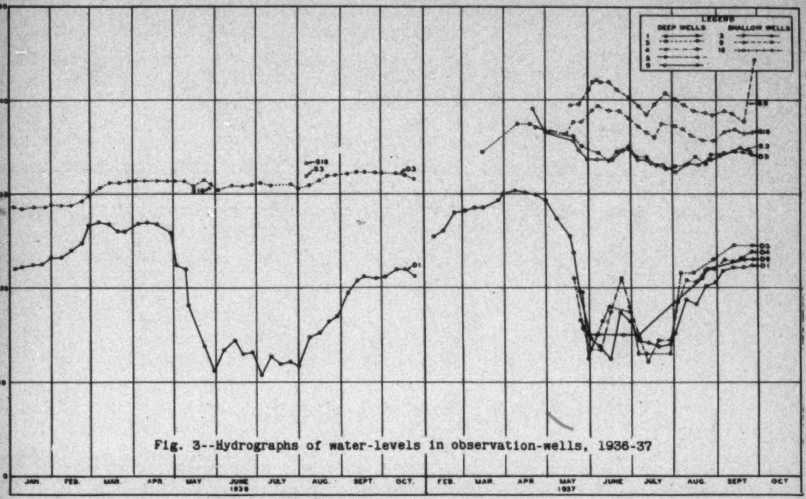


Fig. 3--Hydrographs of water-levels in observation-wells, 1936-37

table and had also 90 "post-hole" wells dug two to four feet below the water-table, which was about ten feet below the ground-surface. He found a diurnal cycle in the water-level fluctuations that he attributed to plant-use. Israelsen and McLaughlin [3, 4], working in an artesian area in Utah, found water-table readings above the soil-surface levels in wells that entered the artesian aquifer. Other wells drilled to graduated depths gave increasingly higher water-levels as they approached the aquifer. Spaeth and Diebold [7], in New York State, found dug-pits unsuitable for water-table studies. Results with soil-tube holes proved more reliable than those with pits. Stout [8], on a reclaimed island in the Sacramento River, found artesian effects similar to those described by Israelsen and McLaughlin [3, 4]. Tidal action in the channels surrounding the area was transmitted to the water-table of the island through a gravelly layer 20 feet below the surface of the tract. This gravel-stratum was in direct contact with the rivers and sloughs. Many other studies could be quoted to recall the wide variation of water-table conditions with which investigators have worked while attempting to evaluate water-supply factors and to achieve other purposes.

Observations on the elevation of the water-surface in the wells of the University Farm, Davis, were begun in 1909. In 1922 several shallow wells, 18 to 25 feet deep and partially cased with 2-inch downspout, were constructed in the farmed area to supply information on the water-table in plots where irrigation-experiments were being conducted. Ever since, water-table data have been collected rather regularly. Figure 1 shows the location of these wells. Figures 2 and 3 present hydrographs of the water-levels in the wells.

With one exception--irrigation-well 3--the shallow wells have a higher water-table than the irrigation or deep wells. Well 3 is an abandoned irrigation-well 125 feet deep. As a concrete plug had been placed at the bottom to keep out water from the porous aquifer, the water that now enters the well comes from shallower depths. At the right side of Figure 3 is illustrated the difference in the water-table levels between this abandoned well and four other irrigation-wells. Although the deep-well and shallow-well water-tables go through a cycle of elevation-changes each year, they are not in phase, the shallow wells lagging behind the phase-cycle of the deep wells. This phenomenon might be explained as follows: Water from winter rains and from early spring irrigations continues to percolate to the upper water-table until June. At about this time, heavy consumption by plants prevents further downward movement. Meanwhile, the deep-well water-table has been lowered, thus increasing the gradient from the shallow-well table to the deep one. The increased head, combined with the use of water by plants, lowers the shallow water-table during the next two or three months. The difference in water-elevations between deep and shallow

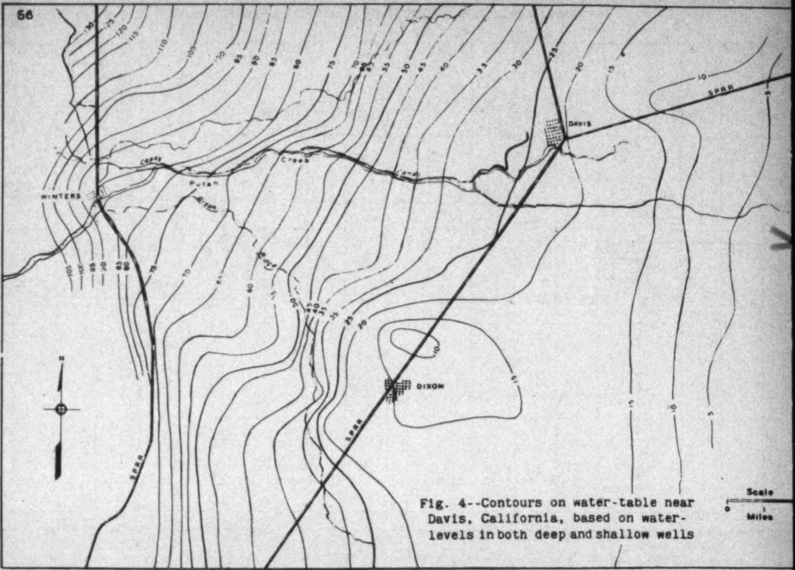
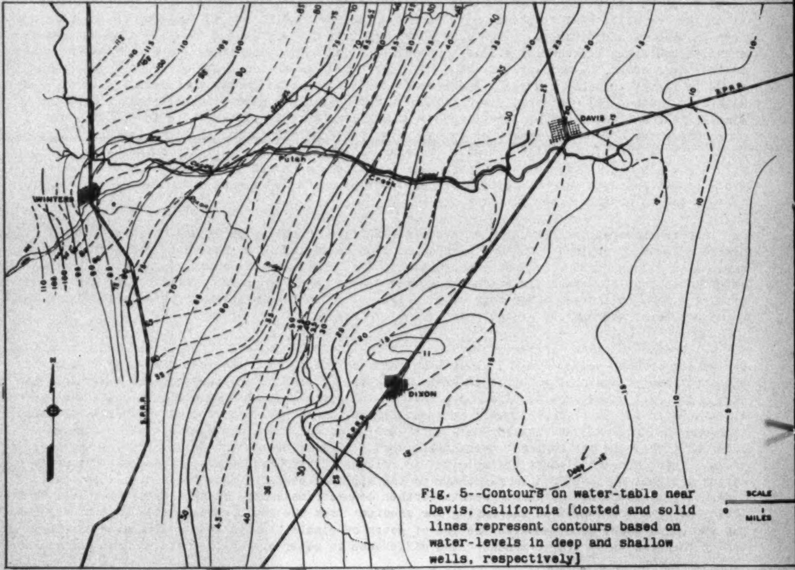

WINTERS
DAVIS
DIXON
Putah Creek
SPRR
N
Scale
0
Miles
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5

Fig. 4--Contours on water-table near Davis, California, based on water-levels in both deep and shallow wells


WINTERS
DAVIS
DIXON
Putah Creek
SPRR
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Deep
SCALE
0
MILES
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
11
10
5

Fig. 5--Contours on water-table near Davis, California [dotted and solid lines represent contours based on water-levels in deep and shallow wells, respectively] wells indicates downward movement of water from the shallow wells.

In 1931, a dry year, water-table studies were expanded from the Davis Campus to include the entire Putah Creek alluvial cone, and since then the water-tables have been read in the fall and spring of each year. In studying the larger area we had to use wells that were readily accessible. As a result, shallow stock and domestic wells were included with the deeper irrigation-wells. According to the data from the University Farm wells, a combination of shallow and deep wells might give a dual record of water-table elevations. The result of plotting the data for all wells measured in the fall of 1936 is shown in Figure 4. The depression about Dixon is the result of local heavy pumping for alfalfa, beets, and similar crops. Figure 5 shows water-table contours from deep and shallow wells separately. The dotted lines represent water-levels in deep wells and the solid contours the water-levels in shallow wells. Because the deep wells were equipped mostly with turbine pumps, permitting no access to the water within, fewer of them than of the shallower wells were tested. Comparison of Figures 4 and 5 shows that the larger number of shallow wells measured has caused the composite water-table contours of Figure 4 to be quite similar to the shallow-well water-table contours of Figure 5.

The difference in water-level in the two types of wells was not apparent when the wells were selected for measurement. Near Dixon we have a record from only one deep well. Hence the shallow wells supply the record of water-table levels for a mile or two about Dixon. Here the water-level in the deep well is above that for the shallow wells, a reversal of the condition found on the Davis Campus.

There is nothing novel in the dual water-table condition at Davis; the so-called perched water-table is recognized in the literature. Apparently, however, many perched water-tables may accrue from retarded downward percolation resulting from a poor conducting zone. This condition is reversed when the zone of highest potential water-table lies below the surface-formations, as in an artesian zone. Here, as shown by Israelsen and McLaughlin [3, 4], the water-table height is influenced by well-depth down to the artesian aquifer. This condition is in contrast with the perched table, where the upper water may be moving, even though very slowly, downward to the lower water-table supplied by the aquifer some distance below the surface. A series of perforated-casing wells ranging in depth from the shallow water-table to the main aquifer might show progressively lower water-tables until the aquifer itself was pierced. In these investigations, therefore, well-depth is highly important.

If a pumped water-supply is being investigated, most of the wells selected for reading should tap the principal water-bearing aquifers, for it is from these wells that the basic data will be secured. This brings up a question regarding the value of the specific-yield figures obtained by studying a group of dissimilar wells. These data are often supported by laboratory studies of small columns of disturbed samples of subsurface materials. As the errors in this type of measurement can be large, one should try to determine whether variations in water represent mainly changes in pressure within the aquifer. For instance, in a large area with a shallow-well water-table overlying a deep-well table, like that found at Davis, could one calculate specific yield of the area by using seasonal volumetric displacement in the deep water-table together with the measured discharge from all pumping plants? Or does the seasonal draw-down in the lower water-table result largely from the reduced head caused by friction and drop in the static head of the aquifer itself, less any contribution from the upper water-table? We believe the latter to be correct.

Although some artesian basins are under high head, the soil-surface is only moist, a fact indicating that the water cannot move rapidly through the material overlying the aquifer. Under such formations there would be little downward movement of water if the pressure in the aquifer were reduced.

In discussing Figure 4 we noted the marked depression in water-table elevations near Dixon during the fall of 1936. By spring this condition had changed, the water-table contours having become nearly parallel and in regular sequence from east to west. This situation is typical of each season in this region. Assuming that such an area might be taken as a unit, wherein the seasonal draw-down of water-table might be related to the seasonal agricultural pumping load, records of several years' power-use were obtained. The portion of the power used for irrigation pumping-load was estimated. As might have been expected, the seasonal draw-down in the area, measured in an all-year pumping well, is almost directly a function of the irrigation-load power-demand for the area. The relation, though interesting as a fact, is not particularly useful in solving the water-supply factors of the particular area because we cannot assume that much water, if any, is supplied the deep wells from the shallow-well water-table since the levels of the latter are below those of the former.

We conclude, from these findings, that the methods used by many investigators in solving water-supply problems may, if generally applied, lead to erroneous results. Since no two areas will be entirely comparable, each must be studied in detail to determine the peculiarities that make each distinct.

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DISCUSSION

HYDE FORBES (Consulting Engineer and Geologist, San Francisco, California)--In Mr. Johnston's presentation of ground-water levels near Davis he showed what applies to all ground-water studies, namely, that the depth of the well must be known and considered in any correlation of well water-levels. In the particular instance shown, the water was pumped from deep wells and spread on the ground in irrigation. There, as in most areas, the transmission or permeability-coefficient of the material is such that temporary perched water-tables exist. The fluctuation-curves of deep-well water-levels follow the seasonal decline due to pump draft. Those for the shallow wells show the building up of a zone of saturation beneath the irrigated area, the water in which is in transit to the lower zone but at a rate lower than the rate of supply from the surface and through the top-soil materials. This action has occurred in many places the writer has studied and where impervious clays do not underlie the top soils.

HYDROLOGY OF VALLEY AREAS ADJACENT TO THE UPPER SAN JOAQUIN RIVER

Gerald H. Jones

Introduction

This paper presents the results of analyses of ground-water conditions and water-supplies underlying lands adjacent to San Joaquin River between Friant and Gravelly Ford Canal and their present utilization and sources of replenishment, based on an intensive field-investigation initiated in the fall of 1936 and continued through the fall of 1938. The investigation was made under the direction of the Water Project Authority of the State of California, by the State Division of Water Resources, under the provisions of a cooperative contract with the United States Bureau of Reclamation, for the purpose of collecting data to be used in the determination of present rights to the use of San Joaquin River water inhering in lands between Friant and Gravelly Ford Canal, which would be affected by the construction and operation of the Central Valley Project. The field-investigation included hydrographic, hydrologic, and topographic surveys and the collection and correlation of available data and information appropriate for use in a determination of the extent of present irrigation-development and sources and amounts of available surface and underground water-supplies.

The data presented herein are from reports of the Division of Water Resources of the State Department of Public Works, Edward Hyatt, State Engineer. These reports were prepared, under the direction of A. D. Edmonston, Deputy State Engineer, by the writer, assisted by I. M. Ingerson, Associate Hydraulic Engineer, and E. C. Marliave, Assistant Engineer-Geologist. The fieldwork was supervised by P. H. Van Etten, Senior Hydraulic Engineer, and I. M. Ingerson, assisted by D. S. Stoner, Associate Engineer, United States Bureau of Reclamation.

Location and extent of area

The general location of lands adjacent to San Joaquin River between Friant and Gravelly Ford Canal, under discussion in this paper, is shown by diagonal hatching on Figure 1. The area lies on the gently sloping valley plain downstream from the westerly margin of the Sierra Nevada. Elevations range from approximately 190 feet near Gravelly Ford Canal to 400 feet in the vicinity of Friant, where the San Joaquin River debouches from the foothills and flows westerly along the bottom of a steep-sided trough below the general level of the adjacent areas. The area investigated includes:

(1) Lands immediately adjacent to San Joaquin River, held in 193 individual ownerships, aggregating approximately 28,500 acres of which 24,000 acres are utilized for agricultural purposes, one-third for pasture, one-third for the production of dry farmed crops, and one-third for the production of irrigated crops.

(2) Lands in Madera County north of lands immediately adjacent to San Joaquin River, held in 228 individual ownerships, aggregating approximately 15,500 acres, of which 12,000 acres were irrigated in 1938 by pumping from ground-water supplies, herein indicated as being replenished by the San Joaquin River.

(3) Lands in Madera County with ground-water replenishment from minor Madera County streams.

(4) Lands in Fresno County south of San Joaquin River with ground-water replenishment from Kings River through Fresno Irrigation District canals.

(5) Lands in Fresno County with ground-water replenishment from minor Fresno County streams.

Scope of investigation

The investigation included studies and analyses of the following subjects:

(1) The geological formation of the area, which indicates the locations, extent, and character of underground reservoirs and transmitting mediums.

(2) The surface water-supplies tributary to the area, which comprise the sources of ground-water replenishment.

(3) Water-supply utilization, including an inventory of the surface-water diversions and applications, quantities pumped from underground, and areas irrigated from the various sources of supply.

(4) Water-level fluctuations in wells as related to changes in flows and stages of adjacent streams and canals, which, in certain instances, indicate sources of ground-water replenishment.

(5) Contours and profiles of the ground-water table, which indicate the direction and extent of ground-water movement.

(6) Changes in saturated-soil volumes, which indicate the relation between pumping drafts and ground-water recharge.

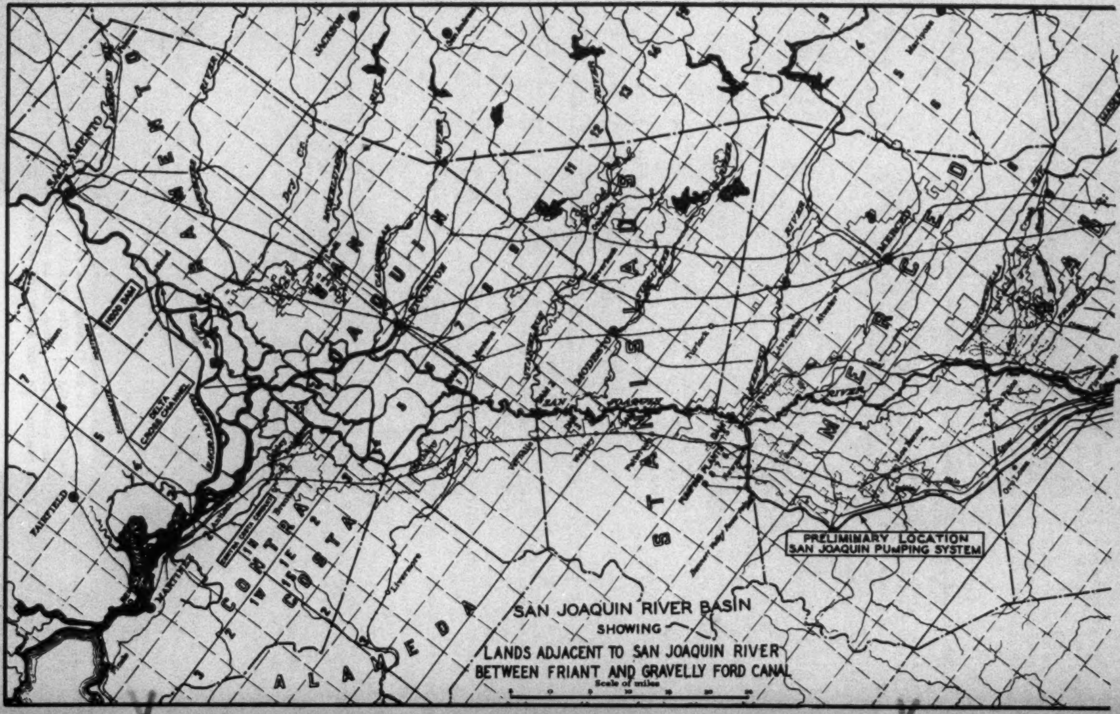
(7) Analyses of losses and accretions in surface-streams traversing the area, pumping drafts for irrigation, changes in saturated-soil volumes, drainage-factors, extent of irrigated areas, and net-use requirements which indicate amounts of water obtained from various sources of supply.

(8) Determinations of relative soluble-salt concentrations in surface and ground-water supplies, which, in certain instances, indicate sources of water-supply.

Geology

The results of a geologic study made by Chester Marliave and Elmer C. Marliave, Engineer-Geologists, to determine the location and extent of underground storage-reservoirs underlying the area adjacent to the San Joaquin River between Friant and Gravelly Ford Canal, have been the subject of a comprehensive geological report. The various geologic formations found in the vicinity are designated by appropriate legend in Figure 2.

From a point above Friant damsite to a point five miles downstream from Friant below Ledger Island, San Joaquin River may be said to be flowing in a granite channel. The northwest bank of the San Joaquin River is composed entirely of solid granite. The granite extends upward to at least 50 feet above normal stream-elevation. Thus, it is not possible for water to escape to the north or northwest in this region. To the south and southeast, granite underlies the thin



SAN JOAQUIN RIVER BASIN
SHOWING
LANDS ADJACENT TO SAN JOAQUIN RIVER
BETWEEN FRIANT AND GRAVELLY FORD CANAL

PRELIMINARY LOCATION
SAN JOAQUIN PUMPING SYSTEM
MADERA CANAL
HOOD DAM
DELTA
CROSS CHANNEL
SACRAMENTO
STOCKTON
MODESTO
MERCED
JACKSON
FAIRFIELD
MARTINEZ
Turlock
Livingston
Atwater
Mariposa
Livermore
SACRAMENTO
SAN JOAQUIN
STANISLAUS
MERCED
CONTRA COSTA
ALAMEDA
MADERA
SAN JOAQUIN RIVER
Dry Cr.
Scale of miles
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5
10
15
20
25

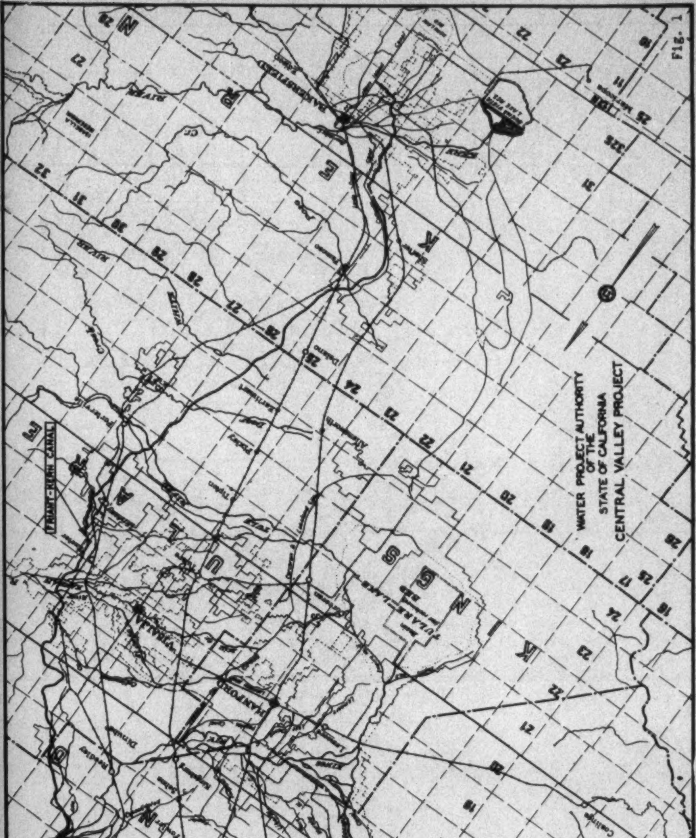

WATER PROJECT AUTHORITY
OF THE
STATE OF CALIFORNIA
CENTRAL VALLEY PROJECT
BAKERSFIELD
TULARE LAKE
HANFORD
VISALIA
FRESNO
FRIANT-KERN CANAL
Coalinga
KINGS
TULARE
KERN
SAN JOAQUIN

Fig. 1

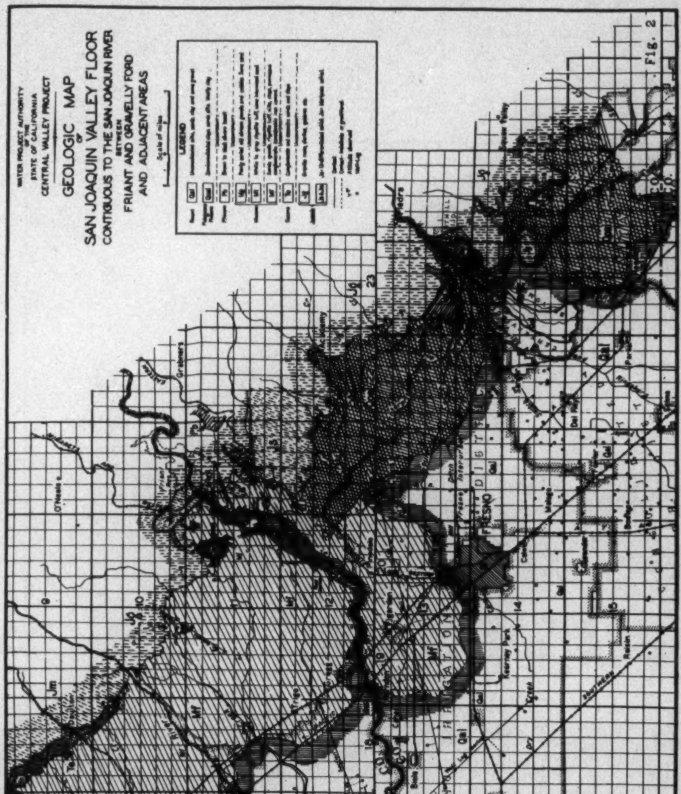
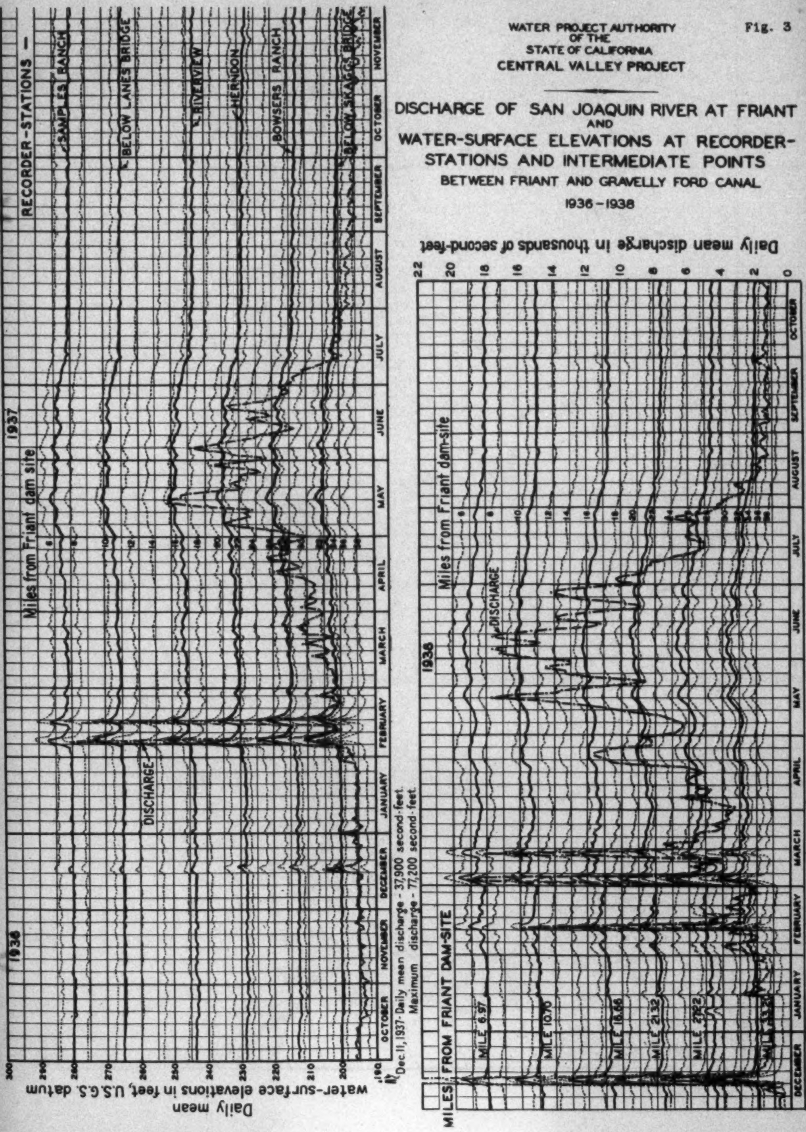

WATER PROJECT AUTHORITY OF THE STATE OF CALIFORNIA
CENTRAL VALLEY PROJECT
GEOLOGIC MAP OF SAN JOAQUIN VALLEY FLOOR
CONTIGUOUS TO THE SAN JOAQUIN RIVER
BETWEEN
FRIANT AND GRAVELLY FORD
AND ADJACENT AREAS
Scale of miles
LEGEND
MADERA
FRESNO
Chowchilla
Qal
Mf
Jm
O'Neals
Friant
Fresno
Kearney Park
Tranquillity
Gravelly
Cottonwood
Canal

Fig. 2

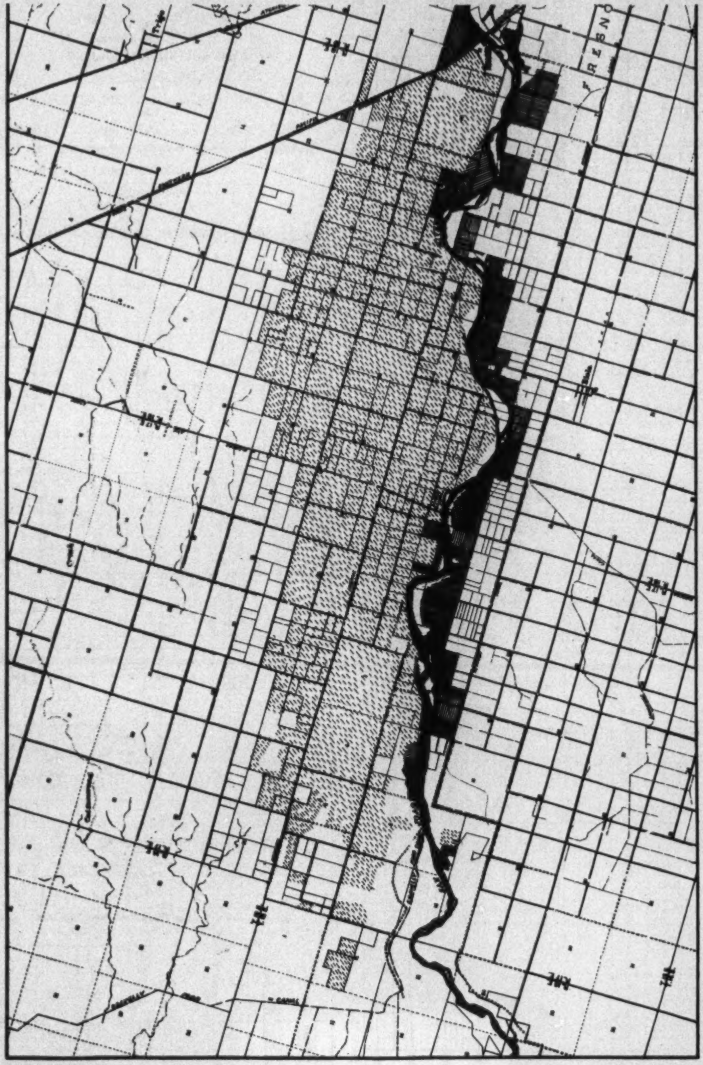
Fig. 3

WATER PROJECT AUTHORITY
OF THE
STATE OF CALIFORNIA
CENTRAL VALLEY PROJECT

DISCHARGE OF SAN JOAQUIN RIVER AT FRIANT
AND
WATER-SURFACE ELEVATIONS AT RECORDER-STATIONS AND INTERMEDIATE POINTS
BETWEEN FRIANT AND GRAVELLY FORD CANAL
1936-1938



Dec. 11, 1937 - Daily mean discharge - 37,900 second-feet.
Maximum discharge - 77,200 second-feet.


RESNO

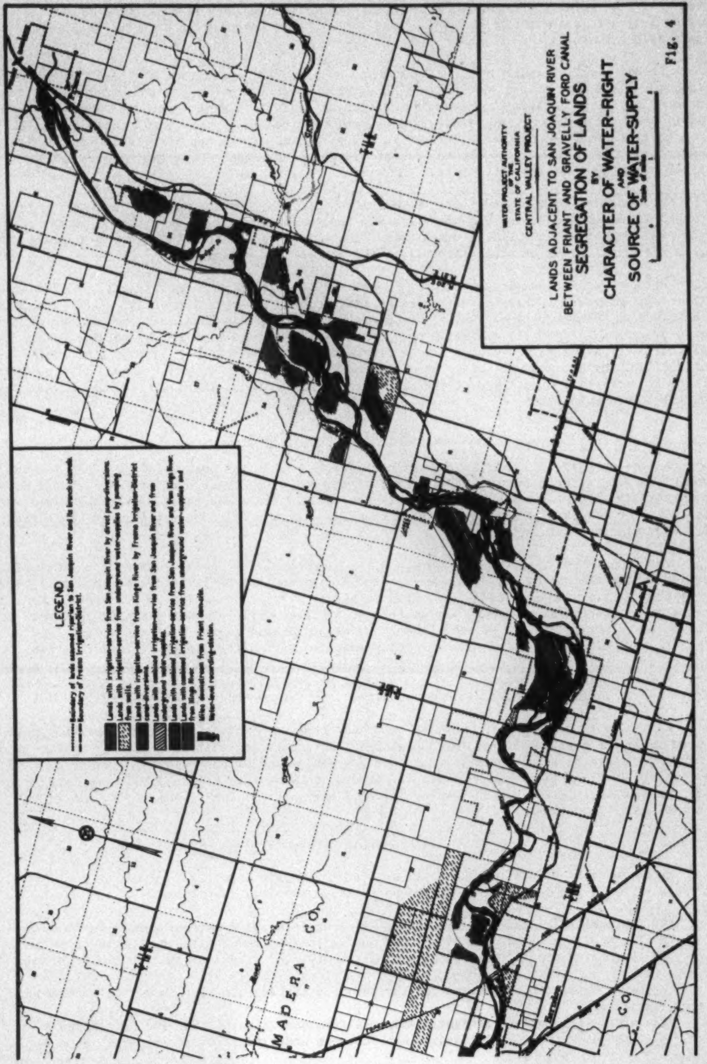

WATER PROJECT AUTHORITY
OF THE
STATE OF CALIFORNIA
CENTRAL VALLEY PROJECT
LANDS ADJACENT TO SAN JOAQUIN RIVER
BETWEEN FRIANT AND GRAVELLY FORD CANAL
SEGREGATION OF LANDS
BY
CHARACTER OF WATER-RIGHT
AND
SOURCE OF WATER-SUPPLY
Scale of miles
LEGEND
Boundary of lands assumed riparian to San Joaquin River and its branch channels.
Boundary of Fresno Irrigation-District.
Lands with irrigation-service from San Joaquin River by direct pump-diversion.
Lands with irrigation-service from underground water-supplies by pumping from wells.
Lands with irrigation-service from Kings River by Fresno Irrigation-District canal-diversion.
Lands with combined irrigation-service from San Joaquin River and from underground water-supplies.
Lands with combined irrigation-service from San Joaquin River and from Kings River.
Lands with combined irrigation-service from underground water-supplies and from Kings River.
Miles downstream from Friant damsite.
Water-level recording-station.
MADERA CO.
CO.

Fig. 4

veneer of the Friant formation at elevations above river-surface so that no contribution by the river is possible in this area. The Friant formation is composed of cemented, sany, tuffaceous lake-laid sediments.

Downstream from Ledger Island the granite dips to the west rather steeply. No evidence is found in the wells drilled west of this point of any granite or basement-complex rock. The river flows westerly from this point but no longer flows in a granite channel. However, it still flows in a more or less impervious channel cut into the Friant formation, designated by appropriate hatching and the letters Mf in Figure 2, and little opportunity is afforded for the water to escape laterally beyond the extent of the recent sands and gravels deposited in the river trough between the bluff-lines.

From a point west of the Friant-alluvium contact near Herndon, a good opportunity is afforded to the waters of the San Joaquin River to escape laterally. This is due to the fact that the overlying recent alluvial sediments are less consolidated than the impervious Friant formation and offer an easier path of travel to the percolating waters.

Between Herndon and Gravelly Ford, 22 and 36 miles downstream from Friant, the San Joaquin River can and does contribute to the ground-water supply of a portion of the area. The main contribution, however, is to the north and northwest of the San Joaquin River, little water, if any, being supplied to the southerly side. The existence of a high ground-water ridge on the southerly, or Kings River, side prevents river-water from percolating in that direction. West of Herndon, the banks of the river are less sharp and high, and in the vicinity of Gravelly Ford there is very little semblance of the sharply incised cut which characterizes the higher regions of the San Joaquin River.

Tributary water-supplies

Water-supplies contributing to the area between Friant and Gravelly Ford Canal include San Joaquin River, minor Madera County streams, minor Fresno County streams, and the canals of Fresno Irrigation District which convey Kings River water. The major portion of the Kings River contribution consists of seepage to the bottom-lands from the ground-water table underlying the District at higher elevations.

The annual runoff of the San Joaquin River at Friant, for the 29-year period 1909-1938, varied from a minimum of 541,000 acre-feet in the season of 1930-1931 to a maximum of 3,592,000 acre-feet in the season of 1937-1938, with an annual average of 1,676,000 acre-feet. For purposes of estimating losses from, and accretions to, the surface-flow traversing the area, the inflow of tributary streams between Friant and Skaggs Bridge gaging-station and the flow of San Joaquin River at that station were carefully measured during the period of investigation. These losses and accretions will be subsequently considered in connection with analyses of pumping drafts for irrigation, changes in saturated-soil volumes, irrigated areas, and net-use requirements, which indicate amounts of water obtained from various sources of supply.

For purposes of estimating pumping lifts and other conditions of diversion, daily mean water-surface elevations of the San Joaquin River at recording stations and intermediate points at two-mile intervals are set forth for the two-year period of observation, October 1, 1936 to October 1, 1938, on Figure 3. It will be noted by reference to Figure 3 that the daily mean and maximum discharges at Friant during the flood of December 11, 1937, were 37,900 and 77,200 second-feet, respectively.

Water-supply utilization

Lands adjacent to San Joaquin River between Friant and Gravelly Ford may be divided into six sources of water-supply segregations or combinations thereof, as follows:

(1) Lands with irrigation-service from San Joaquin River by direct pump diversions.
(2) Lands with irrigation-service from underground water-supplies by pumping from wells.
(3) Lands with irrigation-service from Kings River by Fresno Irrigation District canal diversions.
(4) Lands with combined irrigation-service from San Joaquin River and from underground water-supplies.
(5) Lands with combined irrigation-service from San Joaquin River and from Kings River.
(6) Lands with combined irrigation-service from underground water-supplies and Kings River.

Lands hereinafter indicated as being included within each of the foregoing sources of water-supply segregations are designated by appropriate legend on Figure 4.

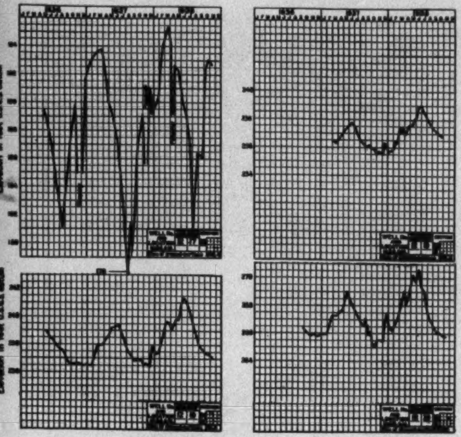


Fig. 5--Water-elevations in wells on lands adjacent to San Joaquin River between Friant and Gravelly Ford Canal

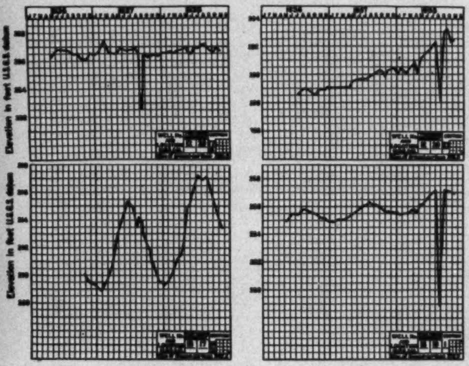


Fig. 6--Water-elevations in wells on lands adjacent to San Joaquin River between Friant and Gravelly Ford Canal

A crop-survey was made for the purpose of determining the location in which the crops of different kinds were grown, the number of acres planted to each of these crops in 1937 and 1938, and the adaptability of certain areas to the growing of crops of different types. More than 80 per cent of the irrigated land is planted to cotton, grapes, and alfalfa. Other irrigated plantings, in order of extent of area, include deciduous orchards, corn, vegetables, and clover.

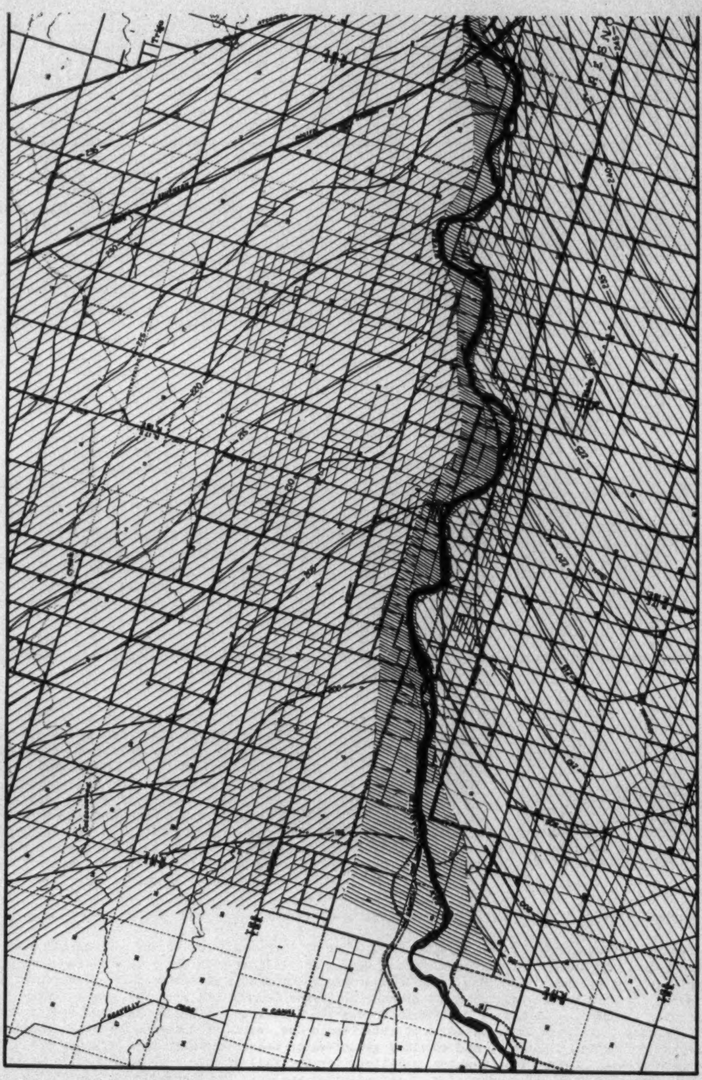
All surface-water diversions from San Joaquin River are made by means of pumping plants which partially serve irrigated areas immediately adjacent to San Joaquin River, aggregating 8,000 acres. The same areas are partially served by pumping from wells. Observations were made of the methods, rates, and periods of diversion for each pumping plant. Surface-diversions average approximately 8,000 acre-feet and quantities pumped from wells about 12,000 acre-feet per year, making the total applications 20,000 acre-feet or 2.5 acre-feet per acre.

North of lands immediately adjacent to San Joaquin River, net areas aggregating 12,000 acres are irrigated by pumping from underground supplies, the principal source of replenishment of which will be hereinafter indicated as being the San Joaquin River. Total applications average 40,000 acre-feet, or 3.3 acre-feet per acre per season.

Of the gross area of 44,000 acres included in the San Joaquin River zone of ground-water replenishment, net irrigated areas total 20,000 acres and total irrigation applications average 60,000 acre-feet, or three acre-feet per acre per season, of which it is estimated two-thirds are consumed and one-third percolates to the zone of saturation and becomes available for reuse.

Ground-water conditions

Detailed observations of ground-water conditions on lands adjacent to the San Joaquin River between Friant and Gravelly Ford Canal started during the fall of 1936 and covered areas with ground-water replenishment from San Joaquin River and considerable portions of those replenished by minor streams in Madera County, minor streams in Fresno County, and with Kings River water distributed through the canals of the Fresno Irrigation District. Prior to that time and continuously since 1921, the State Division of Water Resources, with the cooperation of the Madera and Fresno Irrigation districts, had obtained ground-water measurements in this area and prepared maps showing general ground-water conditions for the fall of each year in connection with the compilation of data and preparation of ground-water analyses for the major portion of the upper San Joaquin Valley.


245
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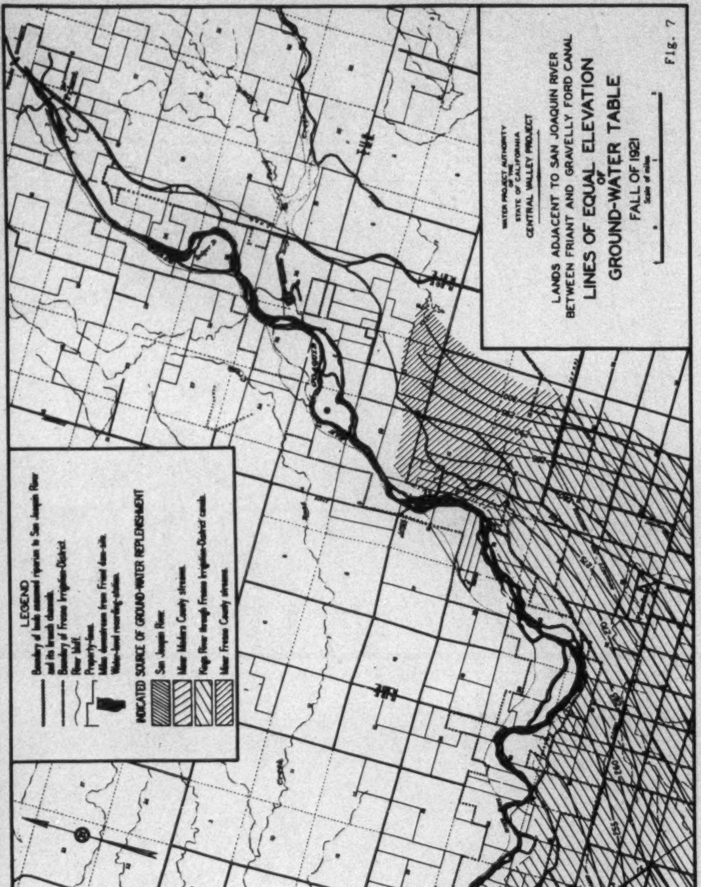
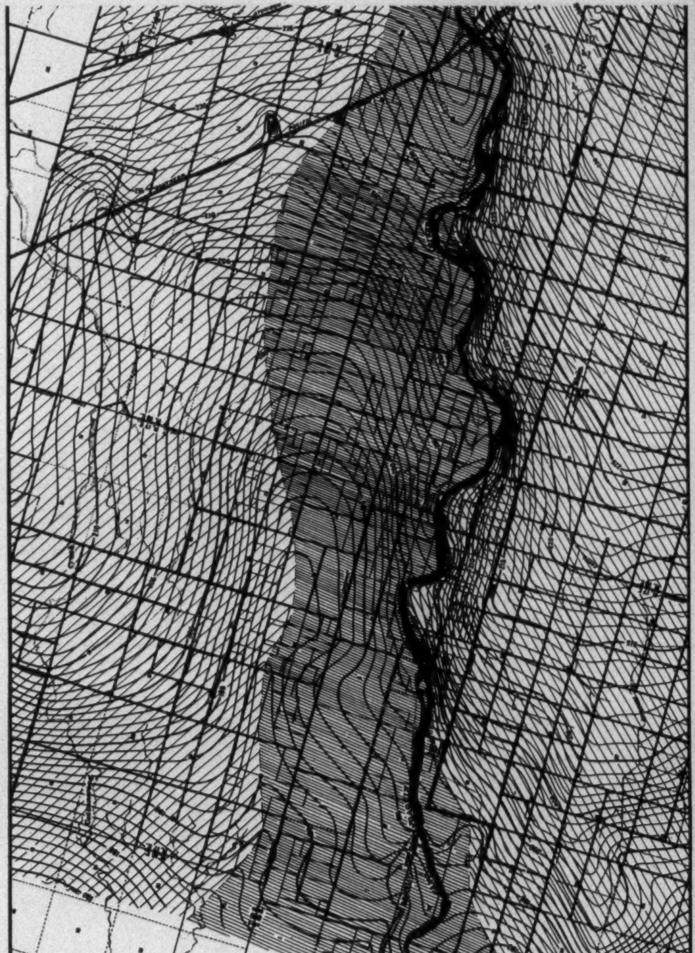

WATER PROJECT AUTHORITY
OF THE
STATE OF CALIFORNIA
CENTRAL VALLEY PROJECT
LANDS ADJACENT TO SAN JOAQUIN RIVER
BETWEEN FRIANT AND GRAVELLY FORD CANAL
LINES OF EQUAL ELEVATION
OF
GROUND-WATER TABLE
FALL OF 1921
Scale of miles
LEGEND
Boundary of lands assumed riparian to San Joaquin River and its branch channels.
Boundary of Fresno Irrigation District.
River bluff.
Property lines.
Miles downstream from Friant dam-site.
Water-level recording-station.
INDICATED SOURCE OF GROUND-WATER REPLENISHMENT
San Joaquin River.
Minor Madera County streams.
Kings River through Fresno Irrigation District canals.
Minor Fresno County streams.
MADERA CO.
CO.

Fig. 7



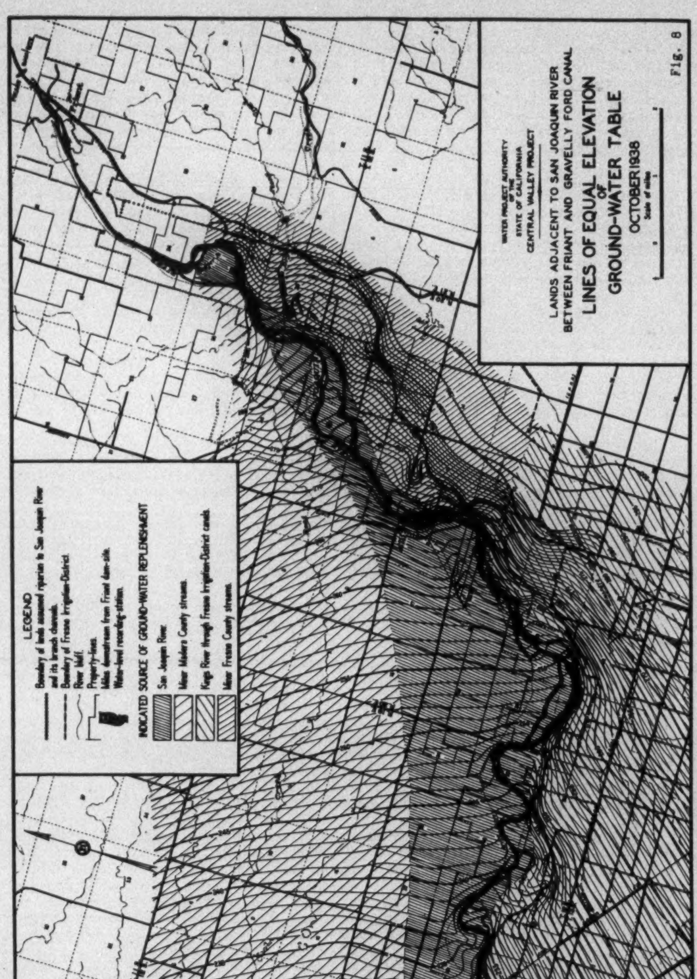

WATER PROJECT AUTHORITY
OF THE
STATE OF CALIFORNIA
CENTRAL VALLEY PROJECT
LANDS ADJACENT TO SAN JOAQUIN RIVER
BETWEEN FRIANT AND GRAVELLY FORD CANAL
LINES OF EQUAL ELEVATION
OF
GROUND-WATER TABLE
OCTOBER 1938
Scale of miles
LEGEND
Boundary of lands assumed riparian to San Joaquin River and its branch channels.
Boundary of Fresno Irrigation-District.
River bluff.
Property-lines.
Miles downstream from Friant dam-site.
Water-level recording-station.
INDICATED SOURCE OF GROUND-WATER REPLENISHMENT
San Joaquin River.
Minor Madera County streams.
Kings River through Fresno Irrigation-District canals.
Minor Fresno County streams.
MADERA CO.

Fig. 8

Ground-water measurements--Complete records were obtained on ground-water elevations on some 300 wells within the area under investigation. Depth-measurements were made biweekly in most of the wells throughout the two-year period of observation. The elevation of the measuring point on each well was accurately obtained by running a closed system of level-circuits and all depth-measurements were converted to elevations in feet, United States Geological Survey Datum. The relation between ground-water elevations in a particular well and daily-mean San Joaquin River water-surface elevations at various points between Friant and Gravelly Ford Canal were determined by comparing the hydrographs of that well with river water-surface elevations previously presented on Figure 3.

Recorded information for each well included depths and elevations of the ground-water, data on ownership, location, type and size of pump, and periods of pumping. Hydrographs of water-elevations in eight wells, each illustrative of a typical geologic or source-of-water-replenishment influence, are presented on Figures 5 and 6. Hydrographs are numbered in accordance with the numbers of the Township, Range, and Section in which the respective well is located. The location of each well within each of the respective sections and its elevation at ground-surface also are set forth on each hydrograph.

(1) Well 12-17-25 is a typical example of wells in the recent alluvium on the Madera County side of the river. It shows a seasonal fluctuation of considerable magnitude and rapid response to changes in San Joaquin River water-level fluctuations.

(2) Well 12-19-33B is in an area predominantly influenced by ditch water, about three-fourths of a mile south of the bluff-line in the Fresno Irrigation District. Nevertheless, the hydrograph of this well shows the influence of the San Joaquin River floods of December 1937 and March 1938, which indicates that underlying porous stringers connect this area with the San Joaquin River.

(3) Well 12-19-34A is typical of wells on the bluff south of the river. Although this well shows the effect of San Joaquin River water-level fluctuations, changes are not as well defined as in Well 12-20-16A, indicating that the response to river water-level fluctuations is partially obscured by the effect of Kings River water-contributions through the canals of the Fresno Irrigation District.

(4) Well 12-20-16A is typical of the many river-bottom wells between the bluffs enclosing the flood-plain of the San Joaquin River. Fluctuations in this well show a definite response to change in river-stage, indicate a more or less direct connection with the river, and promptly reflect winter increments, summer declines, low-flow periods in the fall, and, at times, instantaneous flood-peaks.

(5) Well 12-20-17B is typical of wells located in the Friant formation on the Madera County side of the river. It shows very little seasonal fluctuation and no response to changes in San Joaquin River water-level fluctuations.

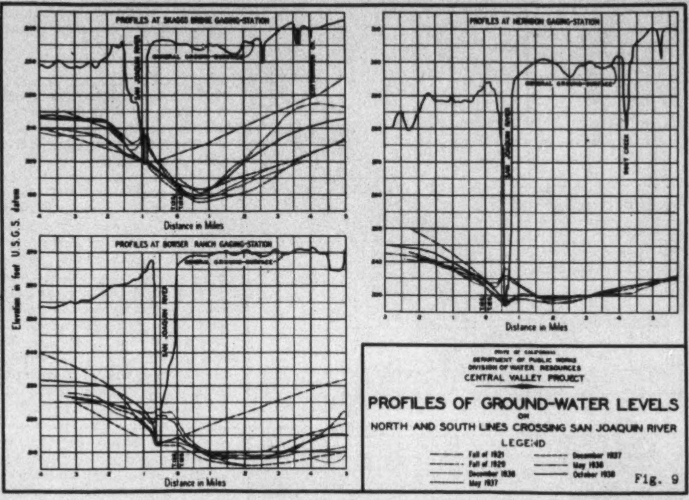
(6) Well 12-20-27 is typical of the wells located in the Friant formation on the south side of the river. The hydrograph of this well shows an apparent cyclic fluctuation and gradual increase in elevation throughout the period of record, thus indicating a constant source of replenishment and a relatively impervious transmitting medium.

(7) The hydrograph of Well 13-17-12A exemplifies the performance of wells in the recent alluvium south of San Joaquin River in the Fresno Irrigation District, where Kings River water constitutes the principal source of ground-water replenishment. The extreme winter lows, summer highs, and regular seasonal fluctuation indicate a porous formation and plentiful water-supply.

(8) Water-levels in Well 13-19-1 clearly reflect the effect of seepage from the adjacent Bullard Canal of the Fresno Irrigation District.

Zones and sources of ground-water replenishment--Ground-water contour-maps and profiles of the area were prepared to depict ground-water elevations at regular intervals during the period of investigation and for previous periods. The first and last of the ground-water maps are presented herein as Figures 7 and 8. Figure 7 was prepared from ground-water measurements made previous to this investigation. Although this Figure does not show the elevations of the water-table underlying the bottom-lands between the bluffs, it does show the elevations of the ground-water underlying the adjacent high lands, indicates the direction of ground-water movement, and permits an approximate segregation of areas of water use in accordance with their respective sources of ground-water replenishment. Figure 8 was prepared from records of water-elevations on some 300 wells, uniformly located throughout the area

On each of the respective Figures, areas with indicated sources of replenishment from San Joaquin River, minor Madera County streams, Kings River through Fresno Irrigation District canals, and minor Fresno County streams have been designated by appropriate legend. The direction of ground-water movement under any particular area is indicated by a downward gradient normal to the lines of equal elevation of the ground-water table.



STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF WATER RESOURCES
CENTRAL VALLEY PROJECT

PROFILES OF GROUND-WATER LEVELS
ON
NORTH AND SOUTH LINES CROSSING SAN JOAQUIN RIVER

Fig. 9

The area in Madera County west of the Santa Fe Railroad, with ground-water replenishment from San Joaquin River, approximately trebled between 1921 and 1929. Prior to 1925, the general water-table sloped toward the river, which acted as a drain. Since that time, the increased installation of wells and operation of pumping plants to irrigate newly developed lands in this area have gradually depleted the underlying ground-water and created a depression some 15 feet lower in elevation than the average low-water level of the San Joaquin River, reversing the direction of movement of the underlying ground-water.

The Kings River zone of replenishment extends beyond the area included in the investigation and its southerly and easterly boundaries are not herein defined. This zone extends upstream along the San Joaquin River to a point approximately 11 miles downstream from Friant and one mile south of Lanes Bridge. Kings River water, distributed through the network of canals and ditches of the Fresno Irrigation District, percolates rapidly into the underlying permeable, alluvial soils. The resulting heavy percolation has created a ridge in the ground-water plain about three miles south of and roughly paralleling the San Joaquin River, from which the ground-water drains perennially into that stream.

Lines of equal elevation of the ground-water table for the high-water periods of May 1937 and May 1938 indicated a movement away from the river in a direction generally northwest on the entire Madera County side of the stream between Ledger Island and Gravelly Ford Canal. This direction of movement from the river is fairly constant throughout the year on a two-mile section in the vicinity of Lanes Bridge, but the rate of movement is believed relatively slow due to the imperviousness of the transmitting medium.

From Herndon west, the lines of equal elevation indicate a continuous and appreciable ground-water movement through the underlying permeable, alluvial soils northwesterly for a distance of from two to three miles toward the bottom of the cone of depression underlying the intensively developed pump-irrigated Madera County area.

Profiles of ground-water levels on north and south lines crossing San Joaquin River at three gaging-stations are presented on Figure 9. These profiles extend about six miles north and three miles south of the river. The first is located at Skaggs Bridge, the second at Bowser Ranch, and the third at Herndon gaging-stations. The profiles show the elevation of the general ground-surface and the elevation of the ground-water table on each of the dates for which ground-water maps have been prepared. Changes in direction of ground-water movement and progressive changes in elevations and gradients are clearly indicated on these profiles.

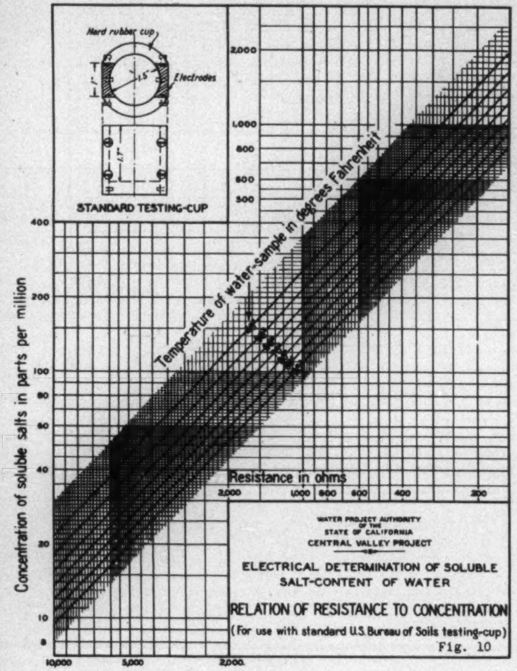


Fig. 10

Soluble salt-content of surface and underground waters--A program of obtaining the concentration of soluble salts in surface and underground waters throughout the area, by the electrical-resistance method, for the establishment of a qualitative relationship between the zones and sources of ground-water replenishment, was made during the late stages of the investigation as an aid in tracing the directions and determining the amounts of ground-water movement. The equipment used in this method included a specially constructed electrical-resistance measuring-apparatus (Wheatstone bridge), a standard United States Bureau of Soils testing-cup, and a thermometer. The ground-water sampling-technique included the selection of operating wells in order to obtain samples representative of the surrounding ground-water and free of pollution. The relation between electrical resistance, in ohms, and concentration of soluble salts, in parts per million, for water-samples of various temperatures is presented graphically on Figure 10. The relationships presented apply only to resistance-measurements of water-samples made in a cylindrical cup having the exact inside dimensions and size and spacing of electrodes shown on the Figure for a standard United States Bureau of Soils testing-cup.

Soluble-salt concentrations in samples of San Joaquin River water from various points between Friant and Mendota and in water-samples from wells, situated along the ground-water slope draining into San Joaquin River from the Fresno Irrigation District, were obtained for the purpose of determining the amounts of Kings River ground-water contribution to the San Joaquin River flow. The results of these observations and determinations will be presented and discussed under "Analyses of ground-water records."

Analyses of ground-water records

The indicated sources of replenishment of the ground-water supplies underlying various portions of the area have been previously discussed. The following discussion deals primarily with the relationship between losses and accretions in surface-streams, pumping drafts for irrigation, changes in saturated-soil volumes, unit net-use requirements, drainage-factors, and a determination of ground-water contributions to, and drafts from, San Joaquin River flow.

Unit net-use requirements and drainage-factors--"Net use" designates the sum of consumptive use from artificial supplies and irrecoverable losses such as ground-water outflow and water consumed in non-cropped areas. "Drainage-factor" designates the proportion of the soil-volume occupied by water extractable by drainage. The determination of unit net-use requirements and the storage-capacities of underlying ground-water reservoirs along the eastern side of the San Joaquin Valley, including lands in Fresno and Madera counties adjacent to San Joaquin River, has been the subject of detailed investigation and study by the State Division of Water Resources during the past 15 years. In the course of these investigations, it was demonstrated that, in areas where the utilization of underground reservoirs is extensively practiced, ground-water levels may be maintained without progressive rise or fall by delivering to such areas average water-supplies equal to their net-use requirements, notwithstanding the fact that the rates of gross pumping may, and often do, exceed the rates of net use. Surface-deliveries and ground-water extractions applied for irrigation in excess of net use percolate to the ground-water and become available for reuse. When the total water delivered to an area exceeds net-use requirements, a ground-water rise occurs. Conversely, a lowering occurs when the delivery is less than the net-use requirement.

Studies of records of water-supply, areas irrigated, and ground-water fluctuations enabled estimates to be made of the deliveries required to meet net use without progressive rise or fall of the water-table. The water-supply used in such studies was the sum of all measurable sources of inflow less all similar measurable items of outflow. The product of the per-acre net-use so determined and the average area irrigated during the period studied, showed the mean seasonal net-supply which would have been necessary to meet the crop-requirements and irrecoverable losses without progressive rise or fall of the ground-water. Where a lowering occurred, the difference between the required net-use supply and the actual inflow indicated the average shortage of supply. The average annual shortage of supply was assumed to be equal to the average annual depletion of ground-water; the drainage-factor, equal to the ratio of the average annual depletion to the average annual volume of soil drained; and the quantity of water required for the resaturation of a particular soil-volume, equal to that extracted during a period of ground-water lowering.

Changes in saturated-soil volumes, losses and accretions in surface-streams traversing the area, and the ground-water contributions to, and drafts from, San Joaquin River flow were computed semiannually during the period of investigation, and the unit net-use requirement and the drainage-factor for lands within the San Joaquin River zone of replenishment estimated to be 2.0 acre-feet per net acre irrigated per season and 18 per cent, respectively.

Other factors affecting the measurement of ground-water contributions to, and drafts from, San Joaquin River flow--Other factors affecting the measurement of contributions of ground-water to, and drafts from, San Joaquin River flow included the following:

(1) Surface-water contributions to uncultivated areas other than tributary stream-flow, namely, (a) rainfall on open water-surfaces and (b) rainfall on adjacent saturated areas.
(2) Evaporation from open water-surfaces and evaporation and transpiration from adjacent saturated areas, namely, (a) river-channel, sloughs, and ponds, (b) lands submerged during flood-stages only, (c) sub-irrigated cropped areas, (d) areas of brush and willows adjacent to the river-channel, (e) saturated sand-bars, and (f) river-bottom pasture-lands.

Inventory of annual contributions to, drafts from, and utilization of all surface and underground water-supplies appertaining to the San Joaquin River zone of ground-water replenishment--During the 12-month period from December 1, 1936, to December 1, 1937, the tributary surface-water supply was approximately 117 per cent of normal. Surface-water supplies entering the San Joaquin River zone of ground-water replenishment were as follows:

Runoff of San Joaquin River at Friant.........	2,230,480 acre-feet
Contribution from Cottonwood Creek............	9,447 acre-feet
Contribution from Little Dry Creek............	17,557 acre-feet
Contribution from Stony Creek.................	2,186 acre-feet
Contribution from Barstow Spillway............	20,210 acre-feet
Total measured runoff above Skaggs Bridge	2,279,880 acre-feet

The measured runoff of San Joaquin River at Skaggs Bridge gaging-station 33.2 miles downstream from Friant damsite was 2,262,340 acre-feet, which would indicate an apparent loss in river-flow of 17,540 acre-feet. Proportionately, the apparent loss in river-flow between Friant and Gravelly Ford Canal 38.5 miles downstream from Friant damsite would be 20,340 acre-feet. During the same period, gross applications and net uses of water on cultivated areas in the San Joaquin River zone of ground-water replenishment aggregated 56,730 acre-feet and 39,240 acre-feet, respectively. All consumptive uses of water included the following:

Net use on cultivated areas......................	39,240 acre-feet
Evaporation and transpiration from open water-surfaces and adjacent saturated areas..........	24,475 acre-feet
Total..........	63,715 acre-feet

Supplies other than ground-water contribution from Fresno Irrigation District, utilized to meet consumptive uses, included the following:

Apparent loss in river-flow between Friant and Grayelly Ford Canal	20,340	acre-feet
Depletion of ground-water	4,925	acre-feet
Rainfall on open water-surfaces and adjacent saturated areas	5,310	acre-feet
Total	30,575	acre-feet
Ground-water contribution from Fresno Irrigation District	33,140	acre-feet

A complete inventory of contributions to, drafts from, and utilization of all surface and underground water-supplies appertaining to the San Joaquin River zone of ground-water replenishment, December 1, 1936, to December 1, 1937, is as follows:

Contributions		
Runoff of San Joaquin River at Friant	2,230,480	acre-feet
Runoff of Cottonwood Creek	9,447	acre-feet
Runoff of Little Dry Creek	17,557	acre-feet
Runoff of Stony Creek	2,186	acre-feet
Kings River water-contribution through Barstow Spillway of Fresno Irrigation District	20,210	acre-feet
Kings River ground-water contribution from Fresno Irrigation District	33,140	acre-feet
Rainfall on open water-surfaces and adjacent saturated areas	5,310	acre-feet
Water applications in excess of net-use requirements	17,490	acre-feet
Net depletion of ground-water	4,925	acre-feet
Total	2,340,745	acre-feet
Drafts		
Gross surface-diversions from San Joaquin River	7,700	acre-feet
Gross quantities pumped from underground	49,030	acre-feet
Evaporation and transpiration from open water-surfaces and adjacent saturated areas	24,475	acre-feet
Total	81,205	acre-feet
Runoff of San Joaquin River at Gravelly Ford Canal	2,259,540	acre-feet

Measurement of Kings River ground-water contribution from Fresno Irrigation District to San Joaquin River flow by the soluble-salt concentration-method--In the previously presented analyses, the estimation of ground-water contributions from Fresno Irrigation District to San Joaquin River flow was dependent on estimates of net use on cultivated areas, drainage-factors, and evaporation and transpiration from open water-surfaces and adjacent saturated areas and on many stream-flow measurements and other measurable factors such as changes in saturated-soil volumes and rainfall on open water-surfaces and adjacent saturated areas. The degree of accuracy of the resulting estimate of the Fresno Irrigation District ground-water contribution of 33,140 acre-feet for the 12-month period, December 1, 1936, to December 1, 1937, is therefore dependent on the degree of accuracy of many measurements and estimates involving relatively large areas and quantities of water. In order to check the degree of accuracy of those measurements and estimates, an independent measurement of the Kings River ground-water contribution from Fresno Irrigation District to the San Joaquin River flow was made by means of the "soluble-salt concentration method" which is based primarily on a study of the relationship between soluble-salt concentrations in samples of San Joaquin River water from various points between Friant and Gravelly Ford Canal and concentrations in samples of water from wells situated along the ground-water slope draining into San Joaquin River from the Fresno Irrigation District.

During October 1938 there were no surface-water contributions to, and practically no drafts from, San Joaquin River between Friant and Gravelly Ford Canal. The flow of the San Joaquin River at Friant averaged 1,375 second-feet on October 19 and 20. The average concentrations of soluble salts in samples of water taken at various points between Friant and Gravelly Ford Canal on these dates were as follows:

0.7 mile downstream from Friant damsite, 21.5 parts per million
10.7 miles downstream from Friant damsite, 23.5 parts per million
22.3 miles downstream from Friant damsite, 28.0 parts per million
31.4 miles downstream from Friant damsite, 32.5 parts per million
36.0 miles downstream from Friant damsite, 40.0 parts per million

Between mile 10.7 and mile 36.0, along the zone of ground-water contribution from Fresno

Irrigation District, the soluble-salt concentration increased uniformly from 23.5 to 40.0 parts per million. The concentrations of soluble salts in samples of water from 22 wells situated uniformly along the ground-water slope draining into San Joaquin River from Fresno Irrigation District during the summer and fall of 1938, varied from 80 to 410 parts per million, with a weighted average of 233 parts per million.

The relationship between the foregoing factors in a measurement of Kings River ground-water contribution to San Joaquin River flows is summarized in the following formula and tabulation.

Formula for estimating Kings River ground-water contribution to San Joaquin River flows--

Q_1 = flow of San Joaquin River at Friant = 1375 second feet

C_1 = soluble-salt concentrations in San Joaquin River water at upstream end of Kings River zone of ground-water replenishment = 23.5 parts per million

C_2 = soluble-salt concentrations in San Joaquin River water at downstream end of Kings River zone of ground-water replenishment = 40.0 parts per million

C_3 = average soluble-salt concentrations in water-samples from wells situated along the ground-water slope draining into San Joaquin River from Fresno Irrigation District = 233.0 parts per million

Kings River ground-water contribution to San Joaquin River flow =

$Q_1 \times (C_2 - C_1)/(C_3 - C_2) = 1375 \times (40.0 - 23.5)/(233.0 - 40.0) = 117$ sec.-ft.

Slope of Kings River ground-water plane toward San Joaquin River

Location of points of measurements in miles downstream from Friant damsite	Difference in feet between elevations of San Joaquin River water-surface and elevations of Kings River ground-water plane at points 1,000 feet from San Joaquin River						
	Dec., 1936	May, 1937	Dec., 1937	May, 1938	Oct., 1938	Weighted average Dec. 1, 1936 to Dec. 1, 1937	Weighted average Oct. 1, 1937 to Oct. 1, 1938
12	3.0	0.5	3.0	0	4.0	2.17	1.92
14	4.0	1.0	4.5	1.0	5.0	3.25	3.12
16	1.5	1.4	1.5	0.2	2.0	1.47	1.04
18	0.6	-0.2	1.2	0	0.8	0.63	0.63
20	1.4	-0.8	2.1	-2.2	2.5	1.02	0.37
22	0	-1.7	0.8	-2.8	1.6	-0.17	-0.57
24	1.5	-2.0	2.0	-0.7	2.5	0.58	0.96
26	0.5	-1.6	0.7	-0.9	0.9	-0.10	0.07
28	0.6	-1.0	1.2	-1.0	2.3	0.37	0.47
30	2.4	-0.5	4.9	-1.5	4.5	2.68	2.17
32	1.4	0	2.2	-0.3	3.5	1.33	1.37
34	2.0	0	1.9	0	5.2	1.28	1.66
36	0.7	-0.2	0.6	0.7	0.4	0.35	0.61
38	0	-0.2	0	0	0.2	-0.07	0.03
Averages	1.40	-0.38	1.90	-0.54	2.53	1.06	0.99

The value of 117 second-feet obtained from the equation represents the Kings River ground-water contribution to San Joaquin River flow for October 19 and 20, 1938. This rate of contribution is not constant throughout the year and varies considerably from month to month and from season to season. The relationship between the rates of contribution for various periods and the rate of contribution determined for October 1938 by the "soluble-salt concentration-method" is proportional to the relationship between the slope of the Kings River ground-water plane underlying lands contiguous to the San Joaquin River for such periods and the corresponding slope in October 1938. The slopes of the Kings River ground-water plane, underlying a strip of land 1,000 feet in width contiguous to the San Joaquin River, normal to the general direction of ground-water movement at two-mile intervals, are set forth in the tabulation for specific months between December 1936 and October 1938, together with the weighted averages for the two 12-month periods, December 1, 1936, to December 1, 1937, and October 1, 1937, to October 1, 1938.

It will be noted from the tabulation that the average slope toward the San Joaquin River was negative during flood-stages on that stream. The average slope toward the river in October 1938 was 2.53 feet per thousand and the weighted average-slopes for the two 12-month periods, December 1, 1936, to December 1, 1937, and October 1, 1937, to October 1, 1938, were 1.06 and 0.99 feet per thousand, respectively.

Average Kings River ground-water contribution to San Joaquin River flow for the 12-month period, December 1, 1936, to December 1, 1937 = (117/2.53) 1.06 = 49 second-feet = 35,475 acre-feet.

The corresponding amount obtained by the previously presented water-inventory method of analysis was 33,140 acre-feet.

Average Kings River ground-water contribution to San Joaquin River flow for the 12-month period, October 1, 1937, to October 1, 1938 = (117/2.53) 0.99 = 46 second-feet = 33,300 acre-feet.

Conclusions

The tributary water-supply in the 1936-1937 season was approximately 117 per cent of normal. It is believed that irrigation-applications in a normal season will slightly exceed those of 1937. An estimate of contributions to, drafts from, and utilization of all surface and underground water-supplies appertaining to the San Joaquin River zone of ground-water replenishment, other than contributions from San Joaquin River water passing Friant damsite, is as follows:

Average annual contributions	
Runoff of Cottonwood Creek	8,000 acre-feet
Runoff of Little Dry Creek	15,000 acre-feet
Runoff of Stony Creek	2,000 acre-feet
Kings River water-contribution through Barstow Spillway of Fresno Irrigation District	10,000 acre-feet
Kings River ground-water contribution from Fresno Irrigation District	35,000 acre-feet
Rainfall on open water-surfaces and adjacent saturated areas	5,000 acre-feet
Water-applications in excess of net-use requirements	20,000 acre-feet
Total contributions	95,000 acre-feet
Average annual drafts	
Gross surface-diversions from San Joaquin River	8,000 acre-feet
Gross quantities pumped from underground	52,000 acre-feet
Evaporation and transpiration from open water-surfaces and adjacent saturated areas	25,000 acre-feet
Total drafts	85,000 acre-feet

From the foregoing, it may be concluded that total contributions to the San Joaquin River zone of ground-water replenishment, from sources other than the San Joaquin River, exceed gross-use requirements by approximately 10,000 acre-feet per year, on the average. However, contributions from Cottonwood, Little Dry, and Stony creeks and rainfall on open water-surfaces and adjacent saturated areas, aggregating 30,000 acre-feet, usually occur during flood runoff seasons, and under present conditions cannot generally be utilized for irrigation. Contributions of Kings River ground-water and surface-spill from Fresno Irrigation District and from applications in excess of net-use requirements, aggregating 65,000 acre-feet, can generally be utilized for irrigation-applications or ground-water replenishment within the area. Therefore, it is concluded that, under present conditions, the average annual use in the San Joaquin River zone of ground-water replenishment of San Joaquin River water passing Friant damsite is approximately 20,000 acre-feet.

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THE USE OF HYDRAULIC MODELS IN THE DESIGN OF SUSPENDED-LOAD SAMPLERS

J. Pat O'Neill

Introduction and analysis of problem--The amount of suspended solid material transported by a stream is usually determined by making measurements of sediment-content and of velocity at many points in the cross-section and integrating the results. The number of sampling points required will depend upon the degree of accuracy necessary, and, according to O'Brien [see 1 of "References" at end of paper], upon our knowledge of turbulent flow and its relation to sediment-transportation.

The suspended-load samplers used for these measurements may be divided into two classifications, depending upon the length of the sampling period. One might be called the integrating or continuous sampler, and the other the instantaneous or grab sampler. Turbulent fluctuations cause the sediment-content at any point in a stream to be continually varying; therefore, only an integrated sample, taken over a period of time long enough to get an average concentration, can truly represent the sediment-content. This integration may be made with a continuous sampler of the suction-nozzle type, which maintains the same velocity at the entrance as the undisturbed velocity of the stream at that point. (Continuous suction-nozzle samplers are now being used in the Cooperative Laboratory of the Soil Conservation Service at the California Institute of Technology.) The mean concentration may also be obtained by combining a number of small grab-samples which show the true instantaneous sediment-content.

Disturbances caused by the sampler will produce changes in the local concentration that vary with the particle-size and distribution. Small changes may be expected when the sediment is fine and uniformly distributed, but larger ones should result when the particles being transported are coarse and the distribution non-uniform. Redistribution of sediment takes place whenever an obstruction causes a stream-filament to deviate from its undisturbed path. In the resulting curvilinear flow, materials having a density greater than water will be accelerated less rapidly and will follow a path with larger radius of curvature. When this occurs, that is, when silt and water at any point are following different paths, redistribution is taking place.

Criterion for comparing samplers--From the above analysis it is apparent that the most representative sample will be obtained when we have the least disturbance to the sampled fluid before it is taken. Therefore, we may judge the merits of a sampling device by the degree to which it meets the conditions set forth in our criterion for the ideal. This requires that no portion of the sampled fluid shall be disturbed by changing its normal velocity, in either magnitude or direction, before it arrives at the point where it is taken. Any sampler will cause some disturbance; therefore, we may evaluate the relative accuracy of such instruments by devising some means of determining the deviation from the ideal.

Hydraulic test-methods--It would be a simple matter to determine by direct test the efficiency or reliability of a sampler if the sediment-concentration at a point in a stream were known. Unfortunately the only means at hand to determine the concentration involves sampling and at once reduces direct tests to a comparison of instruments and techniques. Furthermore, comparing the sediment caught by various instruments is misleading because the character of both the turbulence and the available sediment in the stream or flume affect the results. The practical difficulty of either directly testing or comparing samplers leads to the consideration of other methods of evaluating the performance of such devices. One method that we believe gives an indication of the absolute accuracy, rather than a comparison between samplers of unknown accuracy, is based upon the preceding flow-analysis by which we developed the criterion.

Since the criterion does not permit any disturbance, it becomes necessary to determine the deviation from the ideal; and this can be done by observing the paths of dye-streams injected into the flow. Consequently, in the testing procedure, sampler models were supported in a glass-walled flume and dye-streams were injected upstream at suitable points for observing the disturbance to the filament of fluid entering the sampling space. It seems logical to conclude that there will be no redistribution of sediment if the dye-streams, which follow the flow perfectly, show that no disturbance occurs.

Selection of samplers for testing--After studying various samplers and considering our immediate needs, two types of grab-samplers were selected for hydraulic tests because they seemed most promising for development into instruments that produce little disturbance. One, the horizontal-tube type, consists of a cylindrical or prismatic tube that can be closed to trap a portion of the fluid. The other, the cutter-type sampler, traps a cylinder of fluid between two sealing disks when a spring-actuated cutter tube slides over one disk and strikes the other. The latter type was first used by the late Henry M. Eakin [2] in studying suspended load in the Mississippi.

Hydraulic tests of the Eakin cutter-type sampler--Figure 1 shows one unit of the original Eakin cutter-type suspended-load sampler. A comparison of this sampler with many others indicates that it would cause less disturbance to the flow of the sampled fluid and thereby more nearly satisfy the criterion for the ideal. Those types that do not allow free and undisturbed circulation through the sampling space cannot comply with the criterion.

Figure 2 shows a view looking down into the flume where the hydraulic models were tested in nine inches of water which had a velocity of about three-quarters of a foot per second. The milk bottle above the observation window supplied the dye that was injected through a small tube at points located directly upstream from the center-line of the models and at vertical intervals of one-quarter of an inch. In the foreground one of the sampler models is shown in place ready for a test in which the paths of the dye-streams, as seen from the flume-window, were drawn in relation to the sampler models.

It was evident that the interference to the flow caused by the original Eakin sampler

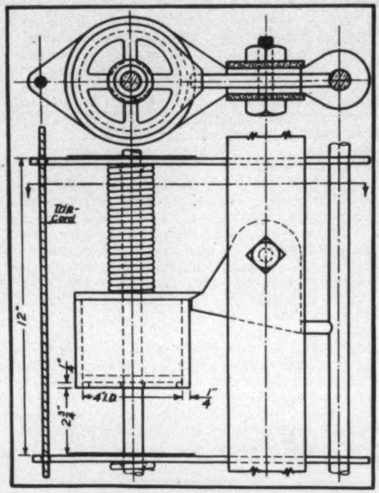

Trip-Cord
12"
1/4"
2 1/4"
4 I.D.
1/4"

Fig. 1--Original Eakin cutter-type suspended-load sampler

Fig. 2--Equipment for testing suspended-load samplers by observing disturbance to filament of fluid entering sampling-space

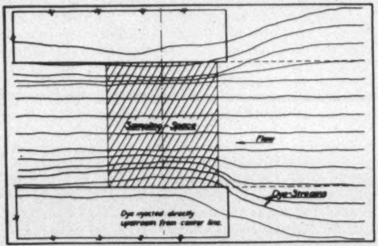

Sampling-Space
Flow
Dye-Streams
Dye injected directly upstream from center line.

Fig. 3--Plot of stream-lines showed curved flow caused by the sampler-body

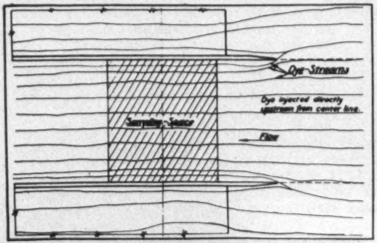

Dye-Streams
Dye injected directly upstream from center line.
Sampling-Space
Flow

Fig. 4--Stream-line plot showing plates for decreasing curvature of flow

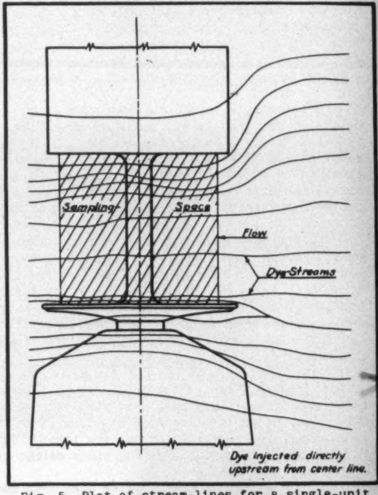

Sampling-Space
Flow
Dye-Streams
Dye injected directly upstream from center line.

Fig. 5--Plot of stream-lines for a single-unit suspended-load sampler could be greatly reduced by removing the trip-cord, eliminating a recess at the top of the sampling space, using a thin cutter-tube, and removing the rod from the center of the sampling space by supporting the mechanism from the rear with a stream-lined housing. A wooden model with outside dimensions conforming to these changes was used in the first run. A study of the resulting flow-pattern revealed the desirability of an additional modification which was incorporated in the model for the second test. The stream-line plots from these tests may be compared in Figures 3 and 4. The upper figure shows clearly that the high-pressure area in front of the body causes the flow to curve toward the sampling space. The lower figure shows that this tendency was decreased when the model was modified by extending thin plates upstream and to the sides (see plates in Fig. 2) so that the body-sections were isolated from the sampling space.

A study of these flow-pictures suggested the possibility of sampling only the least-disturbed part of the space between the plates by isolating the central portion between thin disks (see plates and disks in Fig. 2). Model-tests indicated that this was better than using the plates alone, but the improvement in the flow-pattern was not considered sufficient to warrant the more complicated construction.

Single-unit samplers that are supported in the stream by means of a line were constructed during these studies. Figure 5 shows that the stream-lines around one of these have very little cruvature at the bottom of the sampling space but are quite curved at the top. Flow-correcting plates were not used, however, because a line-suspended sampler will drift and assume an angle to the flow so that their advantages cannot be fully realized. We should not conclude that tilting the sampler has sacrificed the advantages of the cutter-type construction because, with bad orientation, flow through the sampling space is not impaired to the extent that it would be in other types which have a sampling space less accessible to the flow.

Hydraulic tests of the horizontal-tube sampler--The other samplers that were tested with hydraulic models were of the horizontal-tube type. Instruments of this kind have been used that employed gate-values or standard check-valves at the end of 1-inch to 1-1/4-inch-diameter pipe, the valves being spaced 12 to 14 inches apart. The internal resistance of a long, slender tube makes it impossible for the flow-conditions to be unchanged as water passes through it. The lower velocity inside the tube may cause deposition of the coarse particles, and the change in velocity at the entrance will cause some sort of redistribution of the sediment. Because of such undesirable flow-conditions, samplers using long, slender tubes were not considered satis[illegible]ory and consequently they were not tested.

A shutter-mechanism consisting of a plug valve, which traps a portion of water inside the plug, would permit the use of a short tube with a large diameter. For a multiple-unit sampler the horizontal tubes could be placed, one above another, at the desired intervals. With the tube-supporting member of the same size as the plug-valve housing, the tendency would be for more than the normal amount of water to be forced through the tube. However, the internal friction of the tube would oppose this tendency and could be made to exactly balance it by adjusting the tube-length.

Figure 6 shows one of the wooden hydraulic models used in testing the flow-conditions around horizontal-tube samplers. The position and length of the tube could be varied. In the testing procedure a single dye-injector was supported 2-1/2 inches upstream from the entrance of the tube, and the injector adjusted vertically and across the flume until the dye-stream was split by the wall of the tube, one-half going inside and one-half outside. A number of these injection-points which permitted the dye-stream to be divided, were found and located with respect to the axis of the tube. Plots of these readings gave the cross-sectional area, 2-1/2 inches upstream from the sampler, of the stream-filament entering the tube. Changes were made in the sampler-design in order to make the cross-section of the stream-filament equal to the cross-sectional area of the tube.

In the first series of tests a 2-1/2-inch inside-diameter tube was mounted in the 4-1/2-inch cylindrical body shown in Figure 6, and also in a 4-1/4 by 9-inch stream-lined body. The nose-length was kept constant at two inches while the total tube-length was varied from 11 to 15 inches. Plots of the cross-section of the stream-filaments which entered the sampling space showed that, due to some instability that existed for long tubes, changing the length between these limits did not produce a progressively decreasing filament-area.

The plots of all the filament-areas in this run were elongated because the body affects the entrance conditions. Measurements of the filament-elongation for various nose-lengths showed the elongation to be less when the entrance was farther from the body; consequently, the nose-length was increased to one tube-diameter for the final run. The stream-lined body was not used because erratic conditions prevailed with the long tube-lengths required.

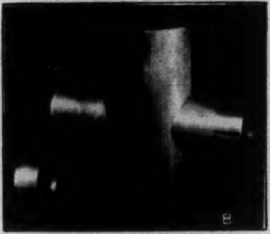


Fig. 6--One hydraulic model used in testing flow-conditions around a horizontal-tube sampler

Fig. 8--Hydraulic model of horizontal tube sampler that uses square tube and short shutter-housing

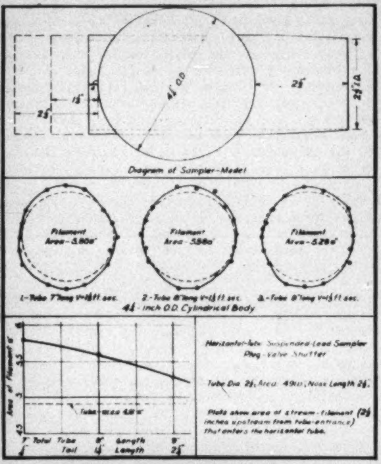

4½" O.D.
2½"
2½" I.D.
1½"
2½"
Diagram of Sampler-Model
Filament Area - 3.80a"
Filament Area - 3.58a"
Filament Area - 3.28a"
1.-Tube 7" long V=1½ ft. sec.
2.-Tube 8" long V=1½ ft. sec.
3.-Tube 9" long V=1½ ft. sec.
4½ - inch O.D. Cylindrical Body
Area of Filament a"
4
3.5
3
4.5
Tube area 4.9 a"
7" Total Tube 8" Length 9"
½" Tail 1½" Length 2½"
Horizontal-tube Suspended-Load Sampler
Plug-Valve Shutter
Tube Dia 2½, Area 4.9a", Nose Length 2½.
Plots show area of stream-filament (2½ inches upstream from tube-entrance) that enters the horizontal tube.

Fig. 7--Test-data for cylindrical-body horizontal-tube sampler for three tail-lengths

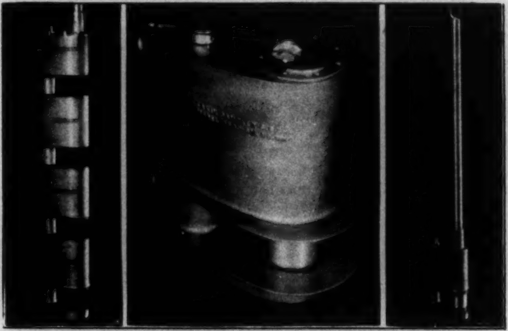


Fig. 9--Close-up view (center) of one unit of later design of multiple-unit Eakin suspended-load sampler; stack (left) of these units arranged for taking samples at vertical intervals of one foot; single unit (right) with supporting rod and shutter-operating mechanism

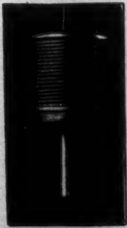
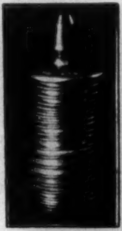


Fig. 10--Single, portable, compact instrument of Eakin type that may be lowered into stream with a line to sample solid material in suspension; open position (left); closed position (right)



The final run was made with the 2-1/2-inch inside-diameter tube in the 4-1/4-inch cylindrical body. The nose-length was adjusted to one tube-diameter and the tail-length was varied by using tube-extensions to produce changes in the filament area. Results are recorded in Figure 7 and they indicate that the filament-area decreases with increasing tube-length. By extrapolation it appears that a tail-length of about 3-1/4 inches would give a filament with an area equal to that of the tube cross-section. However, a longer nose-length would possibly be better since it would put the entrance farther from the disturbed area and reduce the required total tube-length. Before horizontal-tube samplers are constructed, more detailed investigations along these lines should be conducted, using the exact dimensions of the proposed designs.

In the above tests the body-sections between the horizontal tubes had the same size as the plug-valve-shutter housing in order to provide sufficient stiffness for a stack of samplers held rigidly at one end. If a body-section only long enough to enclose the shutter-mechanism is employed, the smaller size will reduce the high-pressure area in front of the body and the low-pressure area behind it. This will make it possible to use shorter tube-extensions and thus produce a sampler that causes less disturbance to the normal flow. A rotary, barrel-type shutter might be used to avoid possible objections to rotating the alignment of the sampling space, as is done in closing the plug-valve sampler; and a square tube could be used in order to secure the largest sample possible in relation to the size of the shutter-housing. These changes would result in a design similar to Figure 8. Tests of this model showed that the plot of the stream-filament cross-section had an area smaller than that of the tube. This indicated that the tube-extensions could be made much shorter--possibly no extension at all behind the body. Due to the anticipated difficulty in producing a sampler of this type that would operate satisfactorily in silt-laden water, further tests were not conducted.

Mechanical design of a multiple-unit sampler--A request of the Hydrologic Division of the Soil Conservation Service for an instrument designed to take sumultaneous samples at vertical intervals of one foot or more brought about the development of the apparatus shown in Figure 9. The one-piece aluminum-alloy housings (center) are bolted together to form a multiple sampler (left) that weighs nine pounds per unit. The bottom plate, rod-adapter, and tripping mechanism (right) were used to test the sampler for proper operation in heavy concentrations of fine sand. It is believed that the end-sections could be used when samples are taken from low bridges or when sampling shallow streams by wading. Handling facilities should be designed to suit the sampling station when more than two units are stacked together, when the water is deep or the velocities high, and when high structures traverse the stream.

Mechanical design of single-unit line-suspended samplers--After an experimental single-unit line-suspended sampler was constructed, a second design was developed which was satisfactory for certain sampling stations. However, it had excessive drift in high-velocity streams and its construction was believed to be more complicated than necessary.

The sampler shown in Figure 10 was designed to overcome these difficulties by reducing the size and frontal area and by increasing the weight. This was accomplished by using a more compact arrangement of parts, using a small supporting cord, constructing the working parts of bronze, and putting the spring on the outside so that the interior could be filled with lead. Any further material increase in compactness is impossible since the top of the sampler is only about one-eighth of an inch above the active portion of the cutter-tube. The weight of the instrument as shown is 6-1/2 pounds which is sufficient for many sampling stations. In high-velocity streams where drift becomes excessive, a stream-lined weight may be attached in place of the cap-nut at the bottom.

Although this design is applicable to any sample volume, the half-pint size illustrated is recommended so that, in low-velocity streams where additional weights are not necessary, it may be handled by some convenient means such as a swordfish line and reel. When the required accuracy demands a larger volume for laboratory analysis, a number of samples may be taken and combined. Accurate results will require this, regardless of the size of the sampler, in order to average the fluctuations in concentration due to turbulence.

Conclusions--Experiments have shown that satisfactory samplers may be built of both the cutter type and horizontal-tube type, provided design-principles based upon properly conducted flow-studies are observed. After making an analysis of sediment-laden flow and studying the results of flow-pattern investigations, it was concluded that the Eakin cutter-type sampler could be made to approach more closely the conditions set forth in our criterion for the ideal, and therefore it was selected for the development of improved mechanical designs.

Acknowledgments--Professor Robert T. Knapp of the California Institute of Technology was

responsible for the initiation of this research and many of the basic ideas used in the hydraulic tests were suggested by him. The work was greatly assisted by a Works Project Administration grant.

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THE SAN DIMAS EXPERIMENTAL FOREST

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In several previous meetings of the South Pacific Division of the Union, various reports concerning the San Dimas Experimental Forest were presented but were not subsequently submitted for publication. The present paper is therefore in the nature of a description of the project and a progress report of accomplishments to date. (Data included in this paper were tabulated and summarized by workers on WPA Project 765-07-3-1.)

The San Dimas Experimental Forest is situated on the south front of the San Gabriel Mountains northeast of Glendora, California, within the boundaries of the Angeles National Forest. It has a gross area of approximately 17,000 acres, including the drainage-basins of Big Dalton and San Dimas Creeks tributary to the San Gabriel River. The Experimental Forest was established in 1933 as a branch of the California Forest and Range Experiment Station of the United States Forest Service and comprises the principal field-unit of a comprehensive research program in the field of watershed-management (forest-influences) in the California region. The objectives of the research program as it applies to the San Dimas Forest are twofold: (1) To study the influence of the chaparral vegetation, soils, geological structure, and other factors upon the yield of usable water; (2) to develop methods of managing or treating the chaparral watersheds to obtain a maximum yield of usable water with a minimum of damaging erosion.

This area was selected after careful search because it is fairly representative of some 5,000,000 acres of chaparral-covered mountains in Southern California. An important further consideration was the existence of the San Dimas and Big Dalton dams, built by the Los Angeles County Flood Control District, since these structures provide the means for measurement of total runoff and erosion from their respective watersheds. In the selection of the areas, and in the subsequent development of the research program, the Experiment Station has had the benefit of advice and consultation of many persons and agencies within and outside of the Forest Service, and particularly of a group of scientists on the faculty of the University of California.

In the past six years the huge task of providing the area as an outdoor laboratory with necessary facilities such as roads, trails, telephone-lines, shelter-cabins, field-headquarters, and experimental equipment for the hydrologic and other phases of the investigative program has required a large share of the time and energies of the small research staff. The construction-program was made possible only with the aid of the Civilian Conservation Corps and the Work Projects Administration. Without these agencies, the Experimental Forest could not have been developed on anywhere near its present scale in this short time.

Experimental installations now in operation, and grouped according to function, are briefly described hereafter, and their general location is shown on the accompanying outline map (Fig. 1) of the Experimental Forest. Table 1 presents a summary of the descriptive data for use with the map.

Precipitation-gages--In all, 380 standard eight-inch gages are distributed over the Forest, principally along contour-trails by methods which aim to sample fairly the various physiographic conditions within each watershed-unit and to eliminate human bias. Excluding about 75 gages that are devoted to special studies not directly concerned with the general measurement of precipitation on the Forest, the density of the gages is roughly at the rate of 15 per square mile,

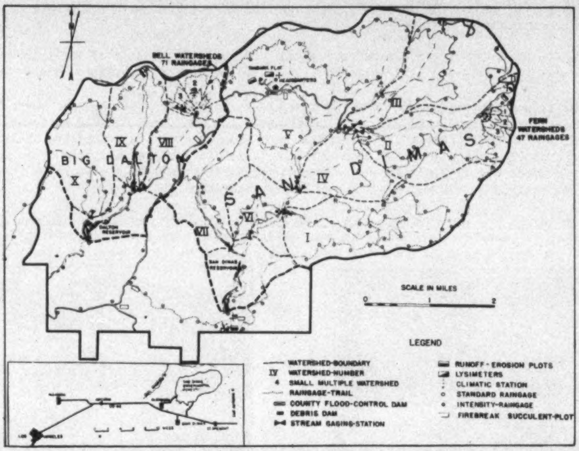
BELL WATERSHEDS
71 RAINGAGES
FERN WATERSHEDS
47 RAINGAGES
BIG DALTON
SAN DIMAS
I
II
III
IV
V
VI
VII
VIII
IX
X
DALTON RESERVOIR
SAN DIMAS RESERVOIR
SCALE IN MILES
0
1
2
LEGEND
WATERSHED-BOUNDARY
IV WATERSHED-NUMBER
4 SMALL MULTIPLE WATERSHED
RAINGAGE-TRAIL
COUNTY FLOOD-CONTROL DAM
DEBRIS DAM
STREAM GAGING-STATION
RUNOFF-EROSION PLOTS
LYSIMETERS
CLIMATIC STATION
STANDARD RAINGAGE
INTENSITY-RAINGAGE
FIREBREAK SUCCULENT-PLOT
LOS ANGELES

Fig. 1--San Dimas Experimental Forest

Table 1--Descriptive data for major, intermediate, and small watersheds in San Dimas Experimental Forest

Watershed	Area, square miles	Area, acres	Range in elevation, feet	No. rain-gages		Stream-gaging stations			Reservoir capacities
				Standard	Intensity	Type	Width flumes, feet	Flume-capac., sec-ft	
Major									(acre-ft)
San Dimas	16.02	10,250	1500-5500	146[a]	18				1,820[b]
Big Dalton	4.47	2,861	1700-3500	47[a]	8				1,160[b]
Intermediate									
San Dimas Drainage									
I Wolfskill	2.43	1,555	1700-5200	23	1	Combination of control-flumes and 90° V-notch weirs, with automatic time-stage recorders and electric depth gages	10 and 3	960	
II Fern	2.18	1,395	2600-5500	25[a]	5		10 and 3	960	
III Upper E. Fork	2.14	1,370	2600-5200	19	1		10 and 3	960	
IV East Fork	5.60	3,584	1900-5500	54[a]	7		15 and 4	2000	
V North Fork	4.32	2,765	1900-4500	37	2		15 and 4	1800	
VI Main Fork	13.40	8,576	1600-5500	121[a]	17		30 and 8	4500	
VII West Fork	1.70	1,088	1600-3100	9	1		10 and 3	710	
Dalton Drainage									
VIII Bell	1.35	864	1900-3500	9[a]	4		10 and 3	780	
IX Volfe	1.17	749	1900-3500	10	1		8 and 3	340	
X Monroe	1.35	864	1800-3400	11	2		10 and 3	780	
Small									(cu.ft)
Bell No. 1	0.121	77	2500-3400	18	1		3	75	10,500
No. 2	0.158	101	2500-3500	23	1		3	75	10,500
No. 3	0.097	62	2500-3400	16	0		3	75	10,000
No. 4	0.058	37	2500-3100	14	1		3	75	100,000
Fern No. 1	0.055	35	4500-5400	13	1		3	75	8,500
No. 2	0.063	40	4500-5400	16	0		3	75	10,000
No. 3	0.084	53	4500-5400	18	1		3	75	10,000

[a] Includes only two gages for each group of small watersheds in Bell and Fern Canyons.

[b] Los Angeles County Flood Control District Reservoir.

or one gage per 43 acres. By reason of physical limitations such as trail-location, the distribution is not uniform as to base area.

There are 26 intensity recording rain-gages. The average density of these is approximately one per square mile although their distribution is varied due to topographic features.

Stream-flow measurements--There are ten major stream-gaging stations, and seven minor stations for small watersheds. As indicated previously, the San Dimas and Big Dalton dams afford opportunity for the measurement of total runoff and erosion from the respective drainages. These main drainages are segregated into ten tributaries termed Intermediate Watersheds, varying in size from about 800 to 8,600 acres. A stream-gaging station with a wide range in capacity has been constructed at the mouth of each of these watersheds.

Within two of the intermediate units, namely, Bell and Fern Canyons, seven small watersheds were selected for more detailed study and for later treatment by manipulation of cover and otherwise. It should be noted that the Fern group of three small watersheds is situated at a

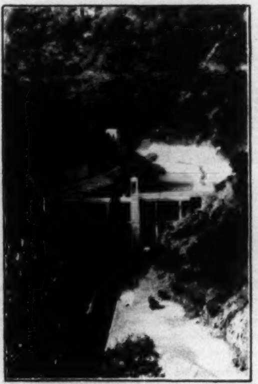

Fig. 2--Installation at mouth of Bell Watershed No. 4 (Material eroded from the 37-acre watershed is measured in gunnite-lined reservoir; gaging-station at head of reservoir provides record of runoff)

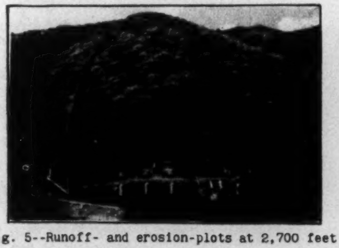

Fig. 5--Runoff- and erosion-plots at 2,700 feet elevation with 20-year-old cover undisturbed (Nine 1/40-acre plots with dimensions of 10 by 120 feet are within enclosure; silt-traps and runoff-measuring devices can be seen at lower end of several plots)

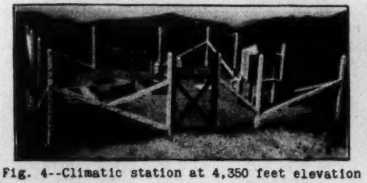

Fig. 4--Climatic station at 4,350 feet elevation in headwaters of San Dimas Creek (Six stations for measurement of air and soil environmental factors are maintained on the Experimental Forest)

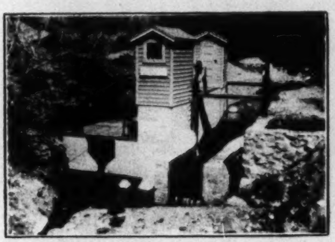

Fig. 3--Stream-gaging station at mouth of Watershed No. 9 (Large flume for measurement of storm-flows with smaller San Dimas flume in tandem arrangement to obtain record of moderate runoff carrying debris; summer flows are measured through 90° V-notch weir at left)

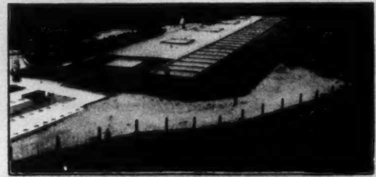

Fig. 6--San Dimas lysimeter-installation (Series of large tanks at right with "unconfined" and root-study lysimeters to left of this group; portion of small and medium lysimeters appear at extreme left)

relatively high elevation (4,500 to 5,400 feet) and, until November 1938, was protected with vegetation more than 50 years old, whereas the Bell group of four watersheds is at lower elevations (2,500 to 3,500 feet) and is covered with chaparral dating from the fire of 1919. A gaging-station and small dam with gunnited reservoir were constructed at the mouth of each of the small watersheds to obtain measurements of both stream-flow and erosion.

Difficulties encountered in stream-flow measurements by reason of the heavy debris-load in most of the streams during storm-runoff literally forced the undertaking of an incidental study to develop a gaging device that would not be rendered useless by flows of this type. The instrument finally developed, now known as the San Dimas stream-gaging flume, was described in a publication by three members of the Experiment Station staff in 1938 [H. G. Wilm, J. S. Cotton, and H. C. Storey, measurement of debris-laden stream flow with critical-depth flumes, Trans. Amer. Soc. Civ. Eng., v. 103, p. 1237, 1938].

A storm of unusually large magnitude in March, 1938, caused damage to stream-gaging stations throughout the Experimental Forest and revealed the need for modifications. The stations as now designed comprise three parts: A large San Dimas flume of concrete or masonry with capacities adequate for expected maximum flows; a smaller San Dimas flume of steel set in concrete or masonry and placed downstream in tandem with the larger flume to handle intermediate stages; and a 90° V-notch steel weir for the measurement of low summer flows that are directed through the weir by means of a by-pass incorporated in the transition between the two flumes. Several of the gaging-stations that have been rebuilt in this manner were subjected to a fair test during the present winter and functioned satisfactorily. The flumes remained clear after the passage of flows that carried considerable gravel and rock debris.

Climatological stations--Six stations have been established at elevations ranging from 1,500 to 5,100 feet, equipped for the continuous measurement and recording of air-temperature and humidity, wind-movement, velocity and direction, evaporation from free water-surface and from Bates evaporimeters, and soil-temperatures at various depths. In addition to other uses, these stations supply the continuous record of environmental conditions that is necessary for the studies of vegetative cover.

Runoff- and erosion-plots--A total of 22 plots, each 1/40 acre in size, has been established in three separate groups at altitudes of 1,500, 2,700, and 4,900 feet, each group being representative of a different type of site and vegetation. Each plot is equipped for the measurement of surface-runoff and erosion, the former by continuous recording instruments. After several years' operation with vegetation undisturbed, these plots are subjected to manipulations of the cover to throw further light on the quantitative effect of vegetation upon runoff, infiltration, and erosion. The group at 4,900 feet elevation was burned off in the fire of November, 1938, and is now yielding valuable records for comparison of the previous cover with the present denuded condition. One pair of the group at 1,500 feet has been periodically denuded by fire for comparison with a fully covered undisturbed pair. The intermediate group at 2,700 feet has just completed the calibration-period and the brush-cover will be subjected to thinning during the present year.

Lysimeters--As an approach to the difficult problem of determining the influence of the forest vegetation upon the percolation of water through the soil and upon water-losses by transpiration and evaporation, there have been installed at the Forest headquarters 120 lysimeters. These simply are tanks filled with native soil in which the dominant species of the chaparral can be grown under observation and with detailed measurements of the water-cycle. The technical term "lysimeter" is an abbreviation of the more correct name "lysiphytometer", that might be freely translated as a percolate-and-plant-meter. The smallest tanks, 72 in number, hold 300 pounds of soil each; the intermediates, 30 in number, hold 1,800 pounds each. These are designed to carry the plants through their early stages of growth from seedling stage to the age of five or ten years, respectively. In both sizes the water-losses are determined by weighing.

A group of 26 large concrete lysimeters, each with surface dimensions of 10.5 by 21 feet, depth of six feet, and surface slope of five per cent, are designed to carry the plants through to maturity for varying periods upwards of ten years. Each of these tanks will hold a considerable group of shrubs and a buffer-planting of the same species will surround each series of tanks. Of these large units, 15 are equipped for the measurement of both rate and total amount of rainfall, runoff, and percolation. In order to evaluate the effect of water-tight tank walls upon soil-moisture and plant-development, a series of five "unconfined lysimeters" has been installed. These are blocks of the lysimeter-soil 14 feet square and eight feet deep (set in excavations of the same dimensions) in which the central soil-masses, ten feet square and six feet deep, are regarded as the actual lysimeters, and the surrounding two feet thicknesses at sides and bottoms constitute pervious "walls" of buffer-soil. This arrangement permits free downward and lateral movement of soil-moisture from and to the lysimeter-block. A fifth group of five concrete lysimeters with one knock-down wall to facilitate washing out the soil for root-studies rounds out the installation.

Completed in the fall of 1937, this installation is still in the initial period of soil-settlement and calibration. It is expected to be ready for the first plantings in the fall of 1940.

Phenological stations--Detailed observations of the annual cycle of growth of all the important species of the chaparral complex are made at 12 stations distributed at different elevations throughout the Experimental Forest. This information, when correlated with climatological records, forges another link in the chain of the water-cycle, permitting correlation between growth-activity and water-use. The question of reproduction and succession in the chaparral type will also be illuminated by this information.

Planting areas--At various elevations and exposures, six half-acre plots have been fenced against deer and rabbits to permit undisturbed experimental planting of species that are less inflammable than the native chaparral and which possess other desirable qualities for watershed cover purposes. Other planting areas are devoted to the testing of vegetation for soil-stabilization and water-flow retardation in fire-denuded and landslip areas.

Other studies--Lines of investigation that require no specific installations include the inventory-surveys and detailed studies of vegetation, soils, and geological structure over the entire Experimental Forest. These are all moving forward and are at present in various stages of completion.

A general vegetation-type map has been completed for the entire Experimental Forest but detailed studies have been completed on only the Bell and Fern small watersheds, aggregating approximately five per cent of the total Forest area. Detailed soil-analysis has been made of the soil used in the lysimeters, and a field-survey of soil-depth and distribution has been made on the three Fern small watersheds. The great bulk of soil-surveying for the Experimental Forest still remains to be done, a laborious and exacting task requiring thousands of borings and sample analyses before the soil-types can be determined and mapped. Detailed but very localized studies have been made of the geological structure at all damsites and stream-gaging stations. Geological maps have also been completed for the Dalton Canyon drainage and for the Fern small watersheds, leaving practically all of the San Dimas drainage still to be completed.

The important subject of ground-water movement has been only lightly scratched by the initiation of flow-records on several springs in the San Dimas drainage. Some attention has been given to the selection of strategic points for the boring of wells to observe ground-water movement and its correlation with geologic structure. The practicability of applying other geophysical methods to this intricate problem is also being considered. The complexity of the underlying rock-structure, the abundance of metamorphic rocks, the extreme and complicated pattern of faulting, and the great depth to which many of the rock-masses have been weathered--all point to the possibility that deep percolation might conceivably reach valley water-tables without ever passing through surface-streams. It is appreciated that under such conditions the record of surface stream-flow for a given mountain watershed might fail considerably from presenting a true picture of water-yield from the area. The study of this phenomena will require careful analysis of data on ground-water levels in the valley below the Experimental Area for correlation with results from the Forest.

The influence of underlying geologic structure upon stream-flow has been very well demonstrated on the Fern Canyon small watersheds of the San Dimas drainage. Uniformly dense chaparral with heavy litter-accumulation covered the three watersheds prior to the fire of 1938. Consistent differences as high as 50 per cent in both maximum flows and seasonal runoff had been observed from these watersheds with cover intact. Some 250 soil-borings showed that although the soil is shallow, averaging only 1.2 feet in depth, it is uniformly distributed over the entire area. It remained for a geologic study to reveal that differences in the underlying strata would permit a maximum of deep percolation in watershed No. 3 and a minimum in No. 1, facts which conformed with their respective characteristics of flow. Since the fire, the runoff from these watersheds has changed radically in character and amount, the latter now being proportionate to the area of the watershed in each instance. With loss of vegetation and litter it appears evident that the lowered infiltration-capacity of the soil on all the watersheds no longer permits the difference in underlying geologic structure to affect the character of runoff as it formerly did.

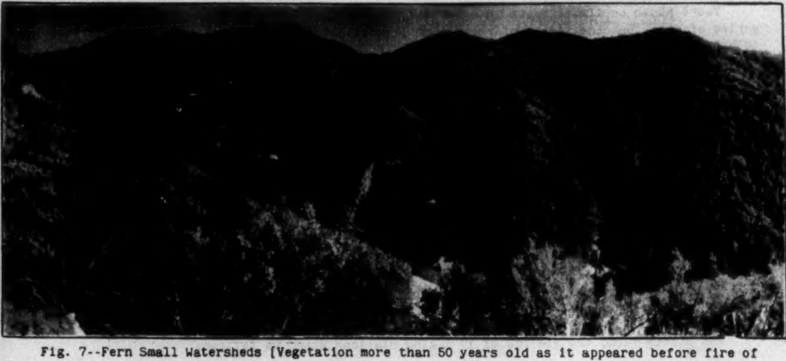

Fig. 7--Fern Small Watersheds [Vegetation more than 50 years old as it appeared before fire of 1938; 47 rain-gages are located on contour-trails at 4700-, 4950-, and 5200-foot elevations on total area of 128 acres]

Fig. 8--Bell Small Watersheds [Area burned in 1919; 71 rain-gages are located on contour-trails at 2500-, 2800-, 3100-, and 3400-foot elevations on total area of 277 acres; stream-gaging station visible at mouth of No. 1 watershed]

General status of data--Notwithstanding the fact that a great deal of time of the technical staff during the past six years has been required for planning and supervising the construction- and installation-program, it has been the policy to begin the taking of records immediately upon completion of any gaging-station or other measuring device. From the outset the obtaining of records has been given precedence over all other activities and has almost always been accomplished by great exertion and exposure on the part of the staff. The help of sub-professional assistants and Civilian Conservation Corps enrollees has been invaluable, and by these means a formidable volume of data covering every phase of the research program described above has been accumulated. The amount of transcription from field-charts to tabular forms, the compilation, checking, and rechecking of all these data can well be understood to be even more formidable if less arduous than the maintenance of the instruments in the field. To cope with this situation there was organized an office project of the Work Projects Administration with some 20 computers under the direction of a member of the Experimental Forest staff. Despite unavoidable changes in the computing personnel and the necessity of training new recruits, the job has gone forward, and it is expected that compilations of the data, under various categories and covering the first five years of records, will be issued in mimeographed or multilithed form during the coming summer. These compilations will be available on request to agencies and individuals who are active or genuinely interested in the field of watershed-hydrology.

There would be little value in a recital of the degree of completeness of the various categories of data, but the status of records of precipitation and stream-flow might be of interest to hydrologists. For precipitation over the Experimental Forest as a whole, the record is as follows:

Storms recorded--

1933-34	21 storms	1936-37	21 storms
1934-35	23 storms	1937-38	18 storms
1935-36	16 storms	1938-39	15 storms
		Total in six years	114 storms

Standard gage-readings--305 regular gages, 75 for special studies; 12-man-days required for one reading

Tabulation, checking, and summarization for period October 1933 to December 1939.................................. 100 per cent complete

Intensity-records--20 to 25 gages for different storms

Tabulation, checking, and summarization for period 1933 to December 1939.. 100 per cent complete

For stream-flow, the records of 17 gaging stations stand as follows:

Stream-flow--17 stations

Tabulation and checking, 1934 to February 1939.............	100 per cent complete
Tabulation, February 1939 to September 1939................	100 per cent complete
Checking, February 1939 to September 1939..................	50 per cent complete
Analysis, 1933 to 1939.....................................	5 per cent complete

Results to date and samples of hydrologic data--The results of precipitation-studies on the Experimental Forest found first expression in the publication of an article in the Monthly Weather Review for June 1939, "Analysis of precipitation measurements on mountain watersheds" by H. G. Wilm, A. Z. Nelson, and H. C. Storey. Another manuscript entitled "Topographic influences upon precipitation" by H. C. Storey was presented before the Sixth Pacific Science Congress in August 1939 and submitted for publication in the Transactions of that meeting. A third manuscript, "An analysis of precipitation records from standard gages, vertical and tilted," originally prepared on the basis of two years of records from 44 gages (22 pairs) in the Bell small watersheds, is now undergoing revision to incorporate two additional years of records. Preliminary conclusions of this study are summarized as follows:

(a) There is a significant difference between the catch in vertical and tilted gages, regardless of exposure; and the theory that vertical and tilted gages would give the same results does not hold true on mountain areas.

(b) The consistently larger catch by tilted gages indicates that this variation is not caused by eddy-currents around gages. The magnitude of differences between the catch in vertical and tilted gages appears to be affected strongly by velocity and direction of wind.

(c) Tilted gages should be expected to give a closer approach than vertical gages to the true catch on mountain watersheds, with the reservation that enough gages must be installed to provide a truly representative sample of the various slopes and exposures existing in the drainage-area studied.

The measurement of stream-flow is one of the most difficult of hydrologic tasks in rough mountainous country of which the Experimental Forest is typical. The satisfactory interpretation of stream-flow records requires detailed knowledge of many factors which in some cases are unknown, and in some quite unattainable. Within the Experimental Forest, accurate and detailed information on the depth and distribution of soil-masses, their water-holding capacities, and infiltration capacities, the percolating capacity of underlying rock-structures, and many other basic facts must be known before correct interpretation of the stream-flow records can be made. While this does not preclude efforts at rational interpretation of the records nor the analysis of hydrographs on the basis of whatever information is available, it does mean that ultimate scientific conclusions regarding water-yield cannot be made until adequate fundamental information is at hand.

Table 2--Annual precipitation and runoff in the San Dimas Experimental Forest

Description				Precipitation in inches			Precipitation and runoff in acre-feet		
Watershed	Average elevation in feet	Area, square miles	Number of rain-gages	5-year normal 1934-38	Precipitation 1938-39	6-year normal 1934-39	Three seasons 1935-37[b]		Runoff in per cent of precip.
							Precipitation	Runoff	
II	4,000	2.18	25[a]	36.50	22.05	34.09	4,242	290	6.8
III	3,900	2.14	19	34.00	22.26	32.04	3,914	490	12.5
IV	3,700	5.60	54[a]	35.02	21.43	32.76	10,451	885	8.5
I	3,400	2.43	23	32.44	19.78	30.33	4,139	403	9.7
V	3,200	4.32	37	32.51	20.62	30.53	7,513	935	12.4
VI	3,000	13.40	121[a]	33.32	20.57	31.20	23,687	2770	11.7
VIII	2,700	1.35	9[a]	32.23	19.90	30.18	2,328	330	14.2
IX	2,700	1.17	10	33.49	20.49	31.32	2,118	261	12.3
X	2,600	1.35	11	33.01	19.70	30.79	2,417	277	11.5
VII	2,400	1.70	9	32.86	19.94	30.71	2,976	302	10.1
San Dimas Canyon above dam	3,500	16.02	146[a]	32.81	20.49	30.76			
Big Dalton Canyon above dam	2,600	4.47	47[a]	32.27	19.47	30.14			
Entire Exp. Forest	3,500	20.49	193[a]	32.69	20.19	30.60			

[a] Includes only two gages for each group of small watersheds in Bell and Fern Canyons.

[b] Seasons of 1934-35, 1935-36, 1936-37.

Table 3--Maximum rainfall-intensities in 5-year period in San Dimas Experimental Forest

Period	Inches per hour	Date	Location
5-minute	4.80	12-30-36	West Fork San Dimas Watershed VII, 2,100 feet
10-minute	3.12	1-15-38	Tanbark Sta., Watershed V, 2,700 feet
15-minute	2.56	1-15-38	Tanbark Sta., Watershed V, 2,700 feet
30-minute	2.04	1-15-38	Bell-Volfe Jnct., Big Dalton, 1,875 feet
1-hour	1.32	3-2-38	Fern SRE Plots, Watershed II, 4,900 feet
2-hour	1.25	3-2-38	Fern SRE Plots, Watershed II, 4,900 feet
12-hour	0.81	3-2-38	Tanbark Sta., Watershed V, 2,700 feet
24-hour	0.48	3-2-38	Tanbark Sta. and Fern SRE Plots

Table 4--Precipitation and runoff storm of February 26 - March 3, 1938, in San Dimas Experimental Forest

Watershed	Area, square miles	Precipitation, inches	Peak-flow	
			Measured cu.ft./sec.	Cu.ft./sec. per sq.mi.
Fern No. 2	0.063	23+	28.85	460
Fern No. 3	0.084	23+	19.00	226
I	2.43	18.33	830[a]	340
II	2.18	20.94	900[a]	410
III	2.14	19.24	800[a]	370
IV	5.60	19.97	2,000[a]	360
V	4.32	18.82	1,800[a]	420
VI	13.40	19.30	5,000[a]	370
VII	1.70	19.44	650[a]	380
VIII	1.35	18.07	500[a]	370
IX	1.17	18.11	350[a]	300
X	1.35	17.81	500[a]	370

[a] Peak-flows of watersheds I-X estimated. Gaging-station approach-walls were over-topped by less than 20 per cent of peak-flow.

Tables 2, 3, and 4 present various records of precipitation and stream-flow for watersheds in the San Dimas Experimental Forest.

California Forest and Range Experiment Station,
U. S. Forest Service,
Berkeley, California

DISCUSSION

L. STANDISH HALL (East Bay Municipal Utility District, Oakland, California)--The writer has been very interested in the data showing a lesser precipitation near the summit of watershed-divides, as indicated in the San Dimas experiment. However, there is some question as to whether this lesser precipitation is not the result of reduced catch due to the exposure of the rain-gages, near the top of the ridges. It is possible that this has been taken into account in the author's inclined rain-gage comparison.

On Strawberry Creek, a small intermittent stream which has a drainage-area of about 600 acres and which flows through the campus of the University of California at Berkeley, California, an intensive study of rain-gages in 1913 and 1914 led to the conclusion that the variation in the catch of the various gages was largely due to a difference in exposure rather than an actual difference in precipitation. The conclusion was drawn from this study that "from a strictly meteorological point of view, the most important result so far seems to be the difficulty, if not the impossibility, of determining the precipitation on a watershed by means of ordinary rain-gages" ["The water resources of Strawberry Creek, Berkeley, California," Mon. Weath. Rev., v. 43, pp. 35-39, and "Note of effects of rain-gage exposure," Mon. Weath. Rev., v. 43, pp. 318-322].

The writer has maintained a series of rain-gages at the San Pablo Dam of the East Bay Municipal Utility District. At this location a strong wind is encountered almost constantly. One standard rain-gage and two rain-gages of a shielded type have been in operation for a period of about ten years. The shielded gages have invariably shown a greater catch, particularly on those days when the anemometer showed a high total wind-movement. A comparison of a portion of the records on one of the sheltered gages has been previously described ["Improving the accuracy of instruments," Civil Engineering, Sept. 1931, p. 1098]. The records for the three gages covering the ten-year period have not been analyzed, so that the exact percentage of increase in precipitation for the shielded gages can not be stated at this time.

REMARKS BY C. F. TOLMAN AND J. F. POLAND ON MR. FORBES' DISCUSSION [see page 34]

Mr. Forbes ascribes the sinking of ground-surface at San Jose to near-surface failure of the "soil-mat" which was overstressed by reduction of water-pressure due to pumping.

The authors of the paper discussed postulate reduction in pressure in all aquifers tapped by wells. This reduction in pressure permits escape of water from the clay into the adjacent aquifers and compaction of clay under the load of the overlying material throughout the zone penetrated by the wells.

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AMERICAN GEOPHYSICAL UNION

REGIONAL MEETING
SOUTH PACIFIC COAST AREA
January 12-13, 1940

PART I-B

WESTERN INTERSTATE SNOW-SURVEY CONFERENCE

REPORTS AND PAPERS

Stanford University, California
January 12, 1940

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FORMATION OF SNOW-CRYSTALS IN THE MOUNTAINS AND IN THE LABORATORY IN JAPAN (A SOUND FILM)

Ukitiro Nakaya

[In the absence of illustrative material, the following "Voice commentary" is provided to show the method of investigation, its results, and the work which still lies overhead.]

At Sapporo, the prefectural capital of Hokkaido, the northernmost island of Japan, winter lasts four months, snowfall is abundant, and conditions are ideal for the study of snow-crystals and snow-drift.

In 1932 Professor Nakaya began to make a detailed study of the physical aspects of snow-crystals, conducting observations and experiments both in the field and in the laboratory.

The greater part of the study of natural snow-crystals was conducted at a cottage half-way up Mt. Tokachi, centrally located in the island of Hokkaido, at an altitude of 1,030 meters above sea-level. During winter the temperature in this vicinity is normally between 10° and 15° C below freezing-point. The snow-crystals observed here are exquisite and delicate, both in form and structure. As the temperature never rises above freezing-point, the difficulty which might be encountered if the crystals melt does not exist. With a little care, the crystals can be handled as one can glass wares of delicate make. When the temperature is 10° below freezing-point, it is possible to work with crystals under a microscope, to divide a twin crystal into its components, to cut a crystal into any desired shape, and to take microphotographs.

The only difficulty arises from the phenomenon of sublimation--the direct evaporation of ice into water-vapor. Due to the action of the crystal's surface-energy, sublimation is accelerated at the sharp edges, or pointed parts, and the sharp outline or delicate design of the crystal is lost rather quickly, even when the temperature is decidedly below freezing. The secret of taking beautiful microphotographs, therefore, lies in the rapidity with which the crystals are handled. Following a general survey of the abundant variety of snow-crystals observable under climatic conditions here, the physical nature of the crystals was investigated, while at the same time observations were undertaken of the mass, falling velocity, and form of individual crystals.

By melting the crystal into a hemispherical droplet on a glass surface covered with a thin film of paraffin wax, the mass was weighed and discovered to be one-tenth of a milligram.

Several years of observation have led to the conclusion that not all snow-crystals are perfect and simple in form. Spacial assemblage of fern-like branches, irregular form, and amorphous particles were frequently observed. Heavy snowfall usually consisted of amorphous particles. Professor Nakaya is of the belief that classifications heretofore made attached importance to only regular crystals or those of simpler form. He proposes a general classification for all types. The numerous variety of crystals is attributed to the complexity of atmospheric conditions. It is believed that the delicate form and design develop in stages while falling through various strata of the atmosphere where diversified weather-conditions exist. This theory led to a new line of research. If the problem of how the various types are formed can be solved, it would be possible to get some information on the structure of the atmosphere accompanying a snowfall by examining the nature of the crystal observed on the Earth's surface. The most important part of this investigation is to know the conditions of the formation of all types of snow. For this purpose an attempt was made in an entirely new field--that of making snow-crystals in the laboratory.

In the first stages of the experiment, frost-crystals were used. An apparatus was designed in which water-vapor is brought up by convection and deposited as frost-crystals on a metal surface cooled with liquid air. By varying the temperature of the metal surface and that of the water, various forms of crystals were produced. Though they were somewhat different from snow-crystals in structure, there were many similarities which offered hints on the problem of artificial production of snow. It was found, however, that since the cooled solid surface used in the apparatus interfered with the full development of crystals, further experiments must be conducted in a larger cold chamber.

Therefore, in 1935, a low-temperature laboratory was built. It was provided with a cold chamber equipped to be cooled down with a refrigerating machine to 50° below freezing. Experiments were largely carried on at room-temperature--about 30° below freezing--although at times it was lowered to 45° below.

The apparatus for producing artificial snow is composed of two concentric glass cylinders held vertically. The warm water-vapor is driven upwards by convection and is condensed into a crystal on a thin rabbit's hair.

Snow-crystals are usually formed by a slow process, the natural ones developing to their final shape after falling a few kilometers through the atmosphere. In order to suspend the crystal in air for a few hours, the rabbit's hair is used. First, the vapor condenses on a minute knob of the hair, thus forming the nucleus of the crystal. The subsequent development, it was found, is determined by the room-temperature and the rate of water-vapor supply.

Various types of natural snow-crystals can be obtained in the laboratory by varying the temperature and that of the water in the tank supplying the vapor. In this way the conditions governing the formation of the many varieties of crystals were clarified to some extent.

In a corner of the same low-temperature laboratory, experiments with the formation of frost on glass plates were conducted simultaneously with the study of artificial snow. These beautiful frost-crystals form, as do snow-crystals, when steam freezes on the cold glass. In addition to the amount of steam and temperature of the atmosphere, another point arises--the surface of the window pane itself. The shape of the frost-crystals varies according to whether the glass is clean or whether it is soiled with finger-marks. In order to find out how they are formed, the camera was slowed up and the two- or three-hour process of crystal-formation was photographed.

The growth of snow-crystals can be observed and studied in the same way. For this purpose the rabbit's hair is stretched on a thin glass frame so that the snow-crystal is fixed in a certain position. In natural snow a hexagonal plate with fern-like extensions at the corners is frequently observed. This type of crystal is formed when the upper layer of the atmosphere is relatively dry and the layer nearest the Earth's surface is sufficiently humid. Artificial production of this type of crystal is achieved by abruptly raising the temperature of the water in the course of the crystal's development. In this manner, almost all types of natural snow can be produced in the laboratory, providing there is some knowledge of the atmospheric conditions under which these crystals are formed.

Under natural conditions, the nuclei of snow are produced in various strata of the atmosphere, their different forms depending on the weather-conditions of the strata through which they fall. In this respect, snow-crystals may be called letters sent from heaven providing, as they do, valuable information. Their form and structure are the hieroglyphics which reveal the conditions prevailing in the various strata of the atmosphere from high altitudes down to the Earth's surface.

These hieroglyphics have been solved to some extent by this series of research, but, with the scant information available at the present stage, no definite conclusions can be reached with respect to the structure of the atmosphere. Many more years of study of the structure of snow-crystals and actual observation of the upper atmosphere of the snowfall are necessary before this difficult, yet interesting, problem is solved.

Hokkaido Imperial University,
Sapporo, Japan

DISCUSSION

J. E. CHURCH--The next step in Professor Nakaya's investigation will naturally be the collecting and photographing of snow-crystals from the cirrus stratum of the atmosphere to the ground. Temperature and humidity will naturally rise as one descends. This increase will leave its impress upon the falling snowflake. Many combinations of humidity and temperature will inevitably be found with corresponding influence upon the form of the flake. These combinations can be created probably more easily in the laboratory than selected in the air. The air-experiments can be used to verify the forms created in the laboratory. The problem will be to capture the snowflake and photograph it before melting or sublimation changes its shape. The meteorological elements can be automatically recorded. Can snowflakes be caught without deformation in an aeroplane? A captive balloon could scarcely rise to the necessary heights. A free balloon is too free from necessary control and probably too expensive for the many ascents required.

This film has been presented by Professor Nakaya and the University of Hokkaido to the

International Commission of Snow and Glaciers for loan to organizations interested in snow. By June 1940 it will have crossed the continent five times and will have been shown ten times or more. Pending the cessation of hostilities, it will be retained in America. In the meantime, Professor Nakaya is enthusiastically making a better film which he plans also to present to the Commission.

A similar study of the variation in snow-crystals with variation in weather-elements has been conducted by W. J. Arnold-Alabieff at the Central Geophysical Observatory, Leningrad, U. S. S. R., since 1936. In each storm the snow-crystals are caught and their types and the frequency of each are carefully determined. Temperature, humidity, and wind are recorded. This method lacks the selectivity of the other and its creative process. It must therefore await the slow chance-combinations of nature. On the other hand, it is inexpensive.

In a position of honor with Japan and Soviet Russia for its comprehensive study of the physics of snow is Switzerland, where the Physikalisch-Meteorologisches Observatorium at Davos and the Swiss Snow and Glacier Commission are studying the evolution of the snow-cover. The Snow and Glacier Commission sent a film on the tension and compression of snow and of avalanche-action to the meeting of the International Commission of Snow held at Washington, D. C., in September 1939. It is now being used for the instruction of the Swiss army against avalanche-perils during its defense maneuvers in the mountains. A duplicate of this film has been offered by the Swiss Commission for 250 Swiss francs ($56.00), the cost of reproduction. Mount Washington Observatory has offered to join with other organizations in procuring the film for public use.

ROUND-TABLE REPORT ON THE ACCURACY OF STREAM-FLOW FORECASTS FOR 1939

NEVADA COOPERATIVE SNOW-SURVEYS--EASTERN SLOPE, CENTRAL SIERRA NEVADA: COMPARISON OF FORECAST AND ACTUAL RESULTS, 1939

H. P. Boardman, George G. Devore, and Leigh Sanford, Forecast Committee

River	Location	Period	Actual runoff		Forecast	
			Acre-feet	Per cent of normal	Per cent of normal	Acre-feet
East Walker a)	Bridgeport Dam	April-August	23,600	32.3	32.9	24,000
West Walker	Chris Flat	April-July	88,800	46.5	44.5	85,000
Carson	Ft. Churchill	April-July	57,700	25.1	23.9	55,000
Truckee b) (exclusive of Tahoe)	Farad	April-July	86,980	26.7	33.8	110,000
			Actual rise, feet	Per cent of normal	Per cent of normal	Forecast rise, feet
Lake Tahoe c)		April 1 to high water	0.51	30.4-	32.7 b)	0.55
				Date		
		Elevation, feet above sea-level	6227.26	5/30-6/4	6/1 b)	6227.30

a) Corrected for storage in Reservoir.
b) Corrected for storage in Boca Reservoir.
c) Assuming gates closed--no outflow.

In the above comparison the forecast-figures were for probable runoff of rivers and rise of Lake Tahoe. The possible minimum estimate which is always given on the regular actual forecast-reports is based on assuming a considerable deficiency in spring and summer precipitation. Actually in 1939 the April-May precipitation at Tahoe City was only about 54 per cent of normal and April-June and April-July only 49 per cent of normal. The deficiency, especially in the April-May period, most of which was in April, helps to account for the deficiency in the runoff of the Truckee River. Had this spring precipitation been normal, the rise of Tahoe and runoff of the Walker and Carson rivers would have been noticeably above the forecast.

Reno, Nevada

NEVADA COOPERATIVE SNOW-SURVEYS: REVIEW OF 1939 FORECAST RESULTS, HUMBOLDT RIVER BASIN, NEVADA

Carl Elges

Stream and location	Average snow water-content, March 1, per cent of normal	Forecast		Actual		Variation
		Per cent of normal	Acre-feet	Per cent of normal	Acre-feet	Per cent of normal
Humboldt River at Palisade (March-July)	69.4	55	140,000	59.3	151,610	+4.3
Lamoille Creek at Power House (April-July)	76.5	75	17,500	82.4	18,790	+7.4

I consider the results obtained as very satisfactory because the Humboldt River represents one of the most difficult streams to forecast. The precipitation during the runoff-period, March through July, was 98.6 per cent of normal. The forecast for Lamoille Creek was made with the provision that the precipitation at the Lamoille station be 6.5 inches during the April-July period. The precipitation during the period was actually 6.35 inches, or about the amount that was given in the forecast.

Nevada Agricultural Experiment Station,
University of Nevada,
Reno, Nevada

CALIFORNIA COOPERATIVE SNOW-SURVEYS, PARTICULARLY WESTERN SLOPE OF SIERRA NEVADA: REPORT OF 1939 FORECASTS

Fred H. Paget

During the winter of 1938-39, 32 different organizations cooperated in the making of snow-surveys in California. These organizations are segregated as follows: National forests, 10; National parks, 4; irrigation-districts, 6; municipal districts, 4; private companies, 2; power-companies, 2; State agencies, 3; and Federal agencies, 1.

Coordinated, standardized, and supervised by the State Division of Water Resources, the snow-surveys were made at 183 snow-courses and, from the data gathered, forecasts were made on 17 different watersheds at 51 runoff stations. Many of these forecasts are based on only a few years' data and are still in the experimental stage, but 28 were considered as being sufficiently reliable for publication.

The year 1938-39 was deficient in precipitation both as snow and as rain also. Like the present year, there was no snowfall to amount to anything during December. During January some snow fell, but the bulk of the snowpack was laid down during two storm-periods--one in February and the other in March.

Following routine procedure, the forecasts of the 1939 snow-runoff from the Sierra were worked up by the Division of Water Resources in Sacramento and published by that Division in the snow-survey bulletin released April 10. The forecasts contained in this bulletin were made in accordance with the snow-cover measured April 1, assuming that the precipitation for the following April would be somewhat below normal in keeping with the character of the previous months of the winter.

April, however, turned out to be so exceedingly dry that when the next regular bulletin was issued a month later it was considered necessary to decrease the earlier estimates to take care of the extreme shortage of precipitation during the month. This modification could readily be done since the direct-method curves used in making the California forecasts allow for a definite evaluation of the effect of subnormal precipitation during April.

Historical figures of the actual 1939 snow-runoff have just recently become available for 23 of the 28 published stations. Of these 23 forecasts, the divergence between the prophecy and the actual runoff is as follows: 0 to 10 per cent, 10; 11 to 16 per cent, 9; 17 to 20 per cent, 1; 21 to 25 per cent, 2; over 25 per cent, 1.

In other words, 43 per cent of the forecasts showed a divergence of less than 10 per cent while 83 per cent showed a divergence not greater than 16 per cent.

The figures for runoff had been available only a few days before the preparation of this report, and the quick studies that we have found time to make so far do not reveal the possible cause of such discrepancies as occur. They may be due to some hold-over storage from the preceding year coupled with inadequate precipitation-data for April from the watershed. At times, like April 1939, the value of having adequate precipitation-stations at high elevations in the watersheds becomes apparent. In most of the watersheds the present precipitation-stations are mostly at low elevations and inadequately portray what is happening up in the snow-area.

Just under half of California's 1939 forecasts fell within the 10 per cent limit of divergence that we strive to hold ourselves to. However, the fact that 19 out of the 23 forecasts came within 16 per cent of the actual makes us feel that, on the whole, the 1939 results were quite satisfactory from a practical standpoint.

Division of Water Resources,
California Department of Public Works,
Sacramento, California

LOS ANGELES DEPARTMENT OF WATER AND POWER: SUMMARY OF 1939 FORECAST FOR OWENS BASIN, CALIFORNIA

James E. Jones

A short statement has been requested as to the experience of the year 1939 in forecasting runoff from snow.

In the Department of Water and Power of the City of Los Angeles, the final estimate is usually the average of the consistent results of several methods of approach, wild answers being discarded. The approach is usually by means of years of similar mean water-content values; by treating each course separately, as if it were the only one in the basin, and then averaging the results; by obtaining an adjusted basin normal water-content by correction for elevation-areas; and by means of the "State direct method."

A variation of the method of similar years is to consider only the six summer months, April to September, and obtain an average for this period. To the average of the summer months, the actual record of the six winter months just past is added and an estimated quantity obtained which represents the expected flow for the hydrographic year.

No single method appears to be good for all conditions that arise. This is the conclusion reached after several years' experience in using the different methods referred to above, although each has justified itself upon occasion. For some years, several methods will give closely similar results.

The Chairman of the Snow-Survey Conference has sent out a brief outline of the points to be covered. The answers to these are as follows:

In the Owens Valley area, the year was a subnormal or lean one; the forecast made was about 62 per cent of a 35-year normal; the runoff-experience was about 88 per cent of the same 35-year normal; the forecast was, therefore, 72 per cent of the runoff-experience, or 26 per cent of normal below the actual runoff. The probable reason for the discrepancy was the fact that the previous year was super-normal and the ground received a good priming, which ran out slowly.

Soil-priming is a subject that is possible of considerable study upon each watershed. The time and volume required for priming, the effect of climatic conditions upon entry into and discharge from the soil, the nature of subsoil as to physical composition and structure, all appear to be largely matters for local study.

The development of a method of forecasting that does not involve considerable personal judgment, and which can be applied to the stream-system without requiring detailed acquaintanceship with the region, is an object that so far has not been attained. In fact, it will probably be worked out only for separate streams after many years' experience has shown what is the cause and effect when closely similar survey-results are followed by runoff-years that vary widely from each other.

Bureau of Water Works and Supply of the City of Los Angeles,
Los Angeles, California

ACCURACY OF FORECASTS AT HUNTINGTON, FLORENCE, AND SHAVER LAKES

W. A. Lang

The Edison Company's Big Creek hydroelectric development is served by three storage-reservoirs, namely, Huntington, Florence, and Shaver Lakes, which impound the runoff of Bear Creek, Mono Creek, South Fork San Joaquin River, Big Creek, Pitman Creek, and Stevenson Creek. The combined area of the six drainage-basins is 449 square miles, 45 per cent of which is above an elevation of 10,000 feet. For the past 12 years, runoff-predictions for this area, based on a function of the precipitation received at several stations at various altitudes, have shown the following errors:

March 1	Maximum error 23 per cent, average error 4.6 per cent
April 1	Maximum error 18 per cent, average error 8.5 per cent
May 1	Maximum error 13 per cent, average error 7.0 per cent

In 1929 the State of California established several high-elevation snow-courses in this area, which they survey once a year (April 1). At that time, in cooperation with the Edison Company, they also established several key-courses which we have surveyed at monthly or semimonthly intervals. Based on data from the key-courses, we have made forecasts for the past four years showing a maximum error of 12.2 per cent and an average error of 6.5 per cent as of April 1.

During the past four years we have made forecasts using both methods as a means of comparison. In general, these forecasts have been made on the first of March, April, and May, although we have made them at two-week intervals when operating requirements made this necessary. We believe that the future prospects for accurately forecasting the runoff from snow-survey data are far superior to the results we can expect to obtain from the more laborious method of computing functions of precipitation. For this reason we have established additional courses and have been attempting to develop our method of forecasting from snow-survey data so that it will meet the requirements of a hydroelectric operating program predetermined as early as March 1 and modified to suit changing weather- and runoff-conditions thereafter.

Forecasts of the combined runoff of Bear Creek, Mono Creek, South Fork San Joaquin River, Big Creek, Pitman Creek, and Stevenson Creek for 1939 were made on March 1, April 1, and May 1. The actual runoff received, based on United States Geological Survey records, was 312,000 acre-feet, while the forecasts were as indicated in Table 1.

Table 1

Date	Function of precipitation		Snow-survey data	
	Acre-feet	Error, per cent	Acre-feet	Error, per cent
March 1	355,000	+13.8	375,000	+20.2
April 1	350,000	+12.2	355,000	+13.8
May 1	317,000	+ 1.6	310,000[a]	- 0.6

[a] This prediction was not actually made although data on hand May 1, 1939, would have given this result.

During 1939 approximately 51 per cent of the seasonal precipitation occurred before the first snow was received. Subsequent to April 1, when it became apparent that the precipitation for the balance of the season would be light, a correction was made to our precipitation-function which resulted in a very close prediction as of May 1. If the same correction had been made to the snow-survey data, a revised forecast for May 1 would have shown an error of less than one per cent (see Table 1).

Southern California Edison Co., Ltd.,
Los Angeles, California

UTAH COOPERATIVE SNOW-SURVEYS: COMPARISON OF FORECASTS AND RUNOFF FOR 1939 FOR STATE OF UTAH

George D. Clyde

Comparison of forecast with runoff on typical Utah streams

[F = forecasted runoff in per cent of normal;
R = runoff as measured in per cent of normal]

Stream	1938				1939				1940	
	Apr.-Sep.		July-Sep.		Apr.-Sep.		July-Sep.		Apr.-Sep.	July-Sep.
	F	R	F	R	F	R	F	R	F	F
Bear River at Harer.......		295.6		55.0	150.0	148.6	40.0	25.2	85.0	25.0
Beaver River at Beaver...	41.0	36.0	8.0	7.6	21.0	16.6	6.0	4.4	24.0	6.0
Big Cottonwood Creek near SLC....	32.0	40.7	6.0	7.5	30.0	27.5	6.0	5.0	25.0	5.0
Blacksmith Fork at Hyrum.......	80.0	59.4	20.0	18.6	45.0	33.7	14.0	11.9	30.0	10.0
Cottonwood Creek at Orangeville.	60.0	60.3	10.0	9.0	50.0	48.0	8.0	6.9	58.0	8.0
Duchesne River at Tabiona	100.0	124.9	23.7	25.4	80.0	74.7	18.0	15.0	60.0	19.0
Huntington Creek near Huntington..	55.0	56.9	14.0	14.6	45.0	39.8	12.0	10.7	50.0	12.0
Logan River at Logan....	128.0	147.1	39.0	43.4	98.0	92.5	32.0	28.7	80.0	29.0
Ogden River, S. Fork near Huntsville..	75.0	60.7	9.0	8.4	46.0	36.4	7.5	6.2	29.0	5.0
Prince River near Helper.	90.0	73.4		23.4	45.0	47.4	15.0	14.2	47.0	14.0
Provo River at Provo....	145.0	180.8	40.0	49.6	100.0	101.6	29.0	28.6	86.0	25.0
Sevier River near Kingston.........	60.0	70.9	14.0	10.4	25.0	29.6	6.0	13.5	25.0	13.0
Virgin River at Virgin...	109.0	124.6	19.0	22.3	60.0	68.3	12.0	33.6	52.0	25.0
Weber River at Oakley...	105.0	132.4	20.0	21.9	100.0	83.7	17.0	14.3	80.0	12.0

Utah Agricultural Experiment Station,
Logan, Utah

SOUTH CONTINENTAL DIVIDE: COMPARISON OF FORECASTS AND RUNOFF IN THE PLATTE, ARKANSAS, RIO GRANDE, AND COLORADO BASINS FOR 1939

R. L. Parshall

In Colorado we have two interesting watersheds, namely, the Arkansas and the Poudre. For the former, the water-content and runoff for 1936, 1937, 1938, and 1939 correlate within very narrow limits, well within five per cent deviation for the Tennessee Pass snow-course records. Also a good relationship is shown by using the Hoosier Pass snow-course records which are for an adjacent drainage-basin. If all our surveys were as consistent as Tennessee Pass, East Portal Twin Lakes Tunnel, and Hoosier Pass, with respect to runoff, we could feel highly pleased with our work.

However, we find some of the data considerably out of line as is evident by the records for the Poudre drainage. For the Arkansas forecast-curve, no correction for precipitation has been applied while for the Poudre we have attempted to so correct the water-content as to better align the plotted points. With such an adjustment we are able to fix a line showing a deviation of about 13 per cent.

We are following another line of attack based on runoff per inch of precipitation in conjunction with water-content of the snow-cover. This study has not progressed far enough as yet to state definitely as to its merits. The mean temperature-relation did not bear fruit, however. The February stream-flow appears to lean in the right direction but to me has no logical connection with the next season's runoff.

I am afraid anything I could offer in the way of forecasts, as based on our records, would not add much to the present published information on this subject. It is not unlikely that after we can secure this season's runoff-data we can then check in with more assurance on what we now have worked out.

Division of Irrigation, Soil Conservation Service, and
Colorado Agricultural Experiment Station,
Fort Collins, Colorado

FORECAST OF INFLOW OF COLORADO RIVER INTO LAKE MEAD AT BOULDER DAM, 1939

E. B. Debler

The May 1, 1939, forecast of inflow to Lake Mead was as follows: Accumulated precipitation during the period October 1938-April 1939, inclusive, compared with similar accumulative records for corresponding periods of the two previous seasons, indicated that the total precipitation to May 1, 1939, was 90 per cent of the average of the previous years, and that the inflow to Lake Mead would probably be 8,000,000 acre-feet between May 1 and August 1, 1939.

Based on water-content of snow, records of this character available since 1936 indicated that the water-content as of May 1, 1939, was 91 per cent of the previous three-year average, or that the probable inflow would be 7,000,000 acre-feet.

While the moisture on May 1, 1939, expressed in per cent of normal for both precipitation- and snow-records, 90 per cent and 91 per cent, respectively, is in substantial agreement, the variation in forecasts based on the two methods is due to the fact that the snow-records cover one year more than do the precipitation-data, namely, 1935-1936, which was a winter of comparatively low snow-cover.

The actual inflow to Lake Mead during May 1 to July 31, 1939, was 5,000,000 acre-feet, or 63 per cent of the expected runoff as indicated by precipitation-records, and 71 per cent of the forecast value based on water-content of snow. This inflow to Lake Mead is approximately 60 per cent of the long-time (38-year) normal.

Forecasts made on February 1, March 1, and April 1, 1939, based on precipitation-data, were more in error than the forecast on May 1 due to comparatively heavy precipitation from October 1938 to January 1939, inclusive, the marked subnormal precipitation after March 1, and exceptionally favorable conditions for loss of accumulated snow by evaporation.

Bureau of Reclamation,
Denver, Colorado

NORTH CONTINENTAL DIVIDE: COMPARISON OF FORECAST AND RUNOFF OF THE UPPER MISSOURI BASIN AT FORT PECK RESERVOIR, 1939

D. B. Freeman

In 1938, on April 1, the snow-pack in the Fort Peck headwaters area was 116 per cent of "normal". However, in view of the dry conditions which had persisted through 1937, and in anticipation of a continued deficiency in precipitation, it was predicted that the runoff above Fort Peck during the four-month period, April to July, 1938, would be only approximately 50 per cent of "normal". This forecast was not subsequently revised. Actually, the precipitation which occurred was above "normal" (130 per cent of "normal") for the first time in several years, and the resulting runoff was 89 per cent of "normal".

In 1939, on April 1, the snow-pack in the Fort Peck headwaters area was 86 per cent of "normal", and, on the assumption that the precipitation would be "normal" or above "normal" during the period April to July, it was predicted that the runoff during this same period would be approximately "normal". The precipitation during April, 1939, was 61 per cent of normal, and by May 1, 1939, the water-content of the snow had decreased to only 40 per cent of the water-content on April 1. The runoff during April was only 82 per cent of "normal".

In view of these circumstances, it was decided to revise the prediction of April 1. Accordingly, it was predicted that in the event the total precipitation during the four-month period, April to July, 1939, proved to be below "normal", the corresponding runoff would not exceed 80 per cent of "normal". The actual total precipitation during the four-month period, April to July, 1939, was only 88 per cent of "normal", and the corresponding runoff was only 60 per cent of "normal".

These comparatively large errors in the predictions for these two years may be attributed largely to the effects of rainfall during the period for which the predictions of runoff were made. A study of the effect of rainfall on runoff during the period for which predictions have been made resulted in the use of a revised procedure in predicting the spring runoff in 1940.

War Department,
Office of Division Engineer,
Missouri River Division,
Kansas City, Missouri

BRITISH COLUMBIA SNOW-SURVEYS: REPORT ON SNOW-SURVEYS AND ACTUAL RUNOFF IN THE UPPER COLUMBIA, FRASER, AND POWELL RIVER BASINS FOR 1939

R. C. Farrow

In a general way, runoff in British Columbia followed the trend indicated by snow-cover measurements, as outlined in my "Report on British Columbia snow-surveys and runoff probabilities" of April 6, 1939. The above-normal snow water-content reported for the coastal belt was reflected in runoff above normal. In the Kootenay and Columbia River basins as mentioned in the above report, the snow water-content varied considerably but averaged about normal; the runoff, however, was fairly consistently below normal, being about 90 per cent.

Data subsequent to the report of April 6 caused a downward revision of some forecasts. Where the changes were material, the interested authorities were notified accordingly.

Table 1 gives a summary of the forecasts made, the accuracy attained, and comments on possible causes of discrepancies.

Table 1

Main basin	Tributary basin	Stream		No. of courses involved	Runoff in per cent of normal		Error	
		Name	At		Forecast	Actual	Per cent of actual	Per cent of normal
Coastal								
Fraser R.	Stave	Stave	Stave Falls	3	128.6	112.8	+13.5	+15.8
Powell R.	.....	Powell	Powell Lake	2	95.1	128.9	-27.2	-33.8
Interior								
Columbia R.	Kootenay	Lardeau	Gerrard	1	87.9	102.0	-12.5	-14.1
Columbia R.	Kootenay	Duncan	Houser	1	84.0	97.7	-13.8	-13.7
Columbia R.	Kootenay	Elk	Elko	2	89.0a)	76.1	+18.1	+12.9
Columbia R.	Kootenay	Slocan	Crescent	1	95.6	93.3	+ 3.6	+ 2.3
Columbia R.	Kootenay	Kootenay	Wardner	3	90.3a)	86.4	+ 5.1	+ 3.9
Columbia R.	Kootenay	Kootenay	Glade	5	94.5a)	90.6	+ 4.7	+ 3.9
Columbia R.	.....	Columbia	Golden	3	94.4a)	91.6	+ 3.3	+ 2.8
Columbia R.	.....	Columbia	Revelstoke	6	93.4a)	93.6	+ 0.1	- 0.2
Columbia R.	.....	Columbia	Trail	14	94.5a)	91.3	+ 3.4	+ 3.2
Columbia R.	Okanagan	Okanagan	Penticton	5	126.4a)	76.2	+68.3	+50.2

a)Forecast of April 1 revised May 1.

Forecasting for coastal streams presents many more difficulties than for those in the interior; the extreme ruggedness and heavy growth of the Coast Range make it very difficult to locate snow-courses where wanted. Over large areas most of the winter precipitation falls as rain, which changes gradually to snow at the higher levels; the snow-covered area changes from year to year, but not in proportion to snow-depth recorded at the snow-courses. Precipitation during runoff is a big factor, and unfortunately the precipitation-stations are located on the lower, and settled, reaches of the basins, giving little or no indication of conditions upstream and at higher altitudes.

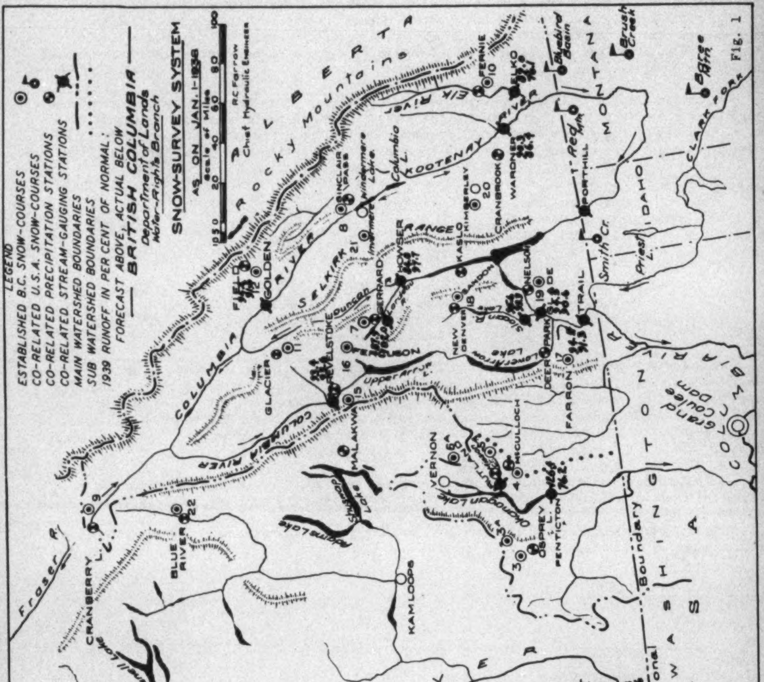

LEGEND
ESTABLISHED B.C. SNOW-COURSES
CO-RELATED U.S.A. SNOW-COURSES
CO-RELATED PRECIPITATION STATIONS
CO-RELATED STREAM-GAUGING STATIONS
MAIN WATERSHED BOUNDARIES
SUB WATERSHED BOUNDARIES
1939 RUNOFF IN PER CENT OF NORMAL; FORECAST ABOVE, ACTUAL BELOW
BRITISH COLUMBIA
Department of Lands
Water-Rights Branch
SNOW-SURVEY SYSTEM
AS ON JAN. 1-1938
Scale of Miles
10 0 20 40 60 80 100
R.C. Farrow
Chief Hydraulic Engineer
ALBERTA
Rocky Mountains
MONTANA
IDAHO
WASHINGTON
Columbia River
Kootenay River
Elk River
Fraser R.
FRASER RIVER
Chilcotin R.
Chilko R.
Chilko Lake
Coast Divide
Coquitlam
Capilano
Harrison L.
Stave Falls
Vancouver Island
Victoria
Vancouver
New Westminster
International Boundary
Okanagan Lake
Shuswap Lake
Adams Lake
Upper Arrow L.
Lower Arrow Lake
Slocan L.
Kootenay L.
Duncan
Windermere Lake
Columbia L.
Selkirk Range
Clark Fork
Grand Coulee Dam
Cranberry L.
Blue River
Kamloops
Williams Lake
Quesnel
Quesnel Lake
Powell Lake
Powell River
Glacier
Field
Golden
Revelstoke
Malakwa
Ferguson
Gerrard
Howser
Kaslo
Sandon
New Denver
Nelson
Deer Park
Farron
Trail
Vernon
McCulloch
Osprey L.
Penticton
Kimberley
Cranbrook
Wardner
Fernie
Elko
Sinclair Pass
Porthill
Smith Cr.
Priest L.
Red Mtn.
Bluebird Basin
Brush Creek
Baree Mtn.

Fig. 1

Predictions for Stave River are improving in accuracy with time and experience. This is the first year of forecast for Powell River. Precipitation during runoff appears to have increased the runoff above that forecast.

Kootenay-Columbia basins--As mentioned in my report of April 6, 1939, excessively high temperatures commenced about the middle of March, and took a heavy toll of snow prior to the end-of-March snow-sampling. This condition was general throughout most of the interior of the Province, and in the Kootenay and Columbia basins represented a typical chinook (Foehn) condition, in which the visible snow-shrinkage was not accompanied by any marked increase in runoff and therefore represented an evaporative loss.

I rather feared that the notable shrinkage which had occurred prior to sampling on many snow-courses might cause serious errors in forecasting. On some tributary streams this was the case, but for the main Kootenay and Columbia forecasts the distribution of snow-courses both in area and in altitude was evidently sufficient to more or less reflect the runoff-potential, since all these forecasts were within reasonable limits of accuracy.

It will be noted, however, that, with the exception of the Lardeau and Duncan rivers, all the Kootenay and Columbia forecasts were too high (as indicated by their "plus" errors). I attribute this uniformity of error to the fact that the high prevailing March temperatures would take a heavier toll of the snow at low than at high elevations. In fact, the ground was bare by the end of March at elevations where snow is normally found a month later. This would reduce the total area of snow-fields and moreover reduce the total potential runoff from those areas below the snow-courses to a greater degree than from the areas above the courses and, by thus upsetting the normal balance, cause the average expectation of runoff as indicated by snow water-content to exceed actual runoff.

The Lardeau and Duncan basins are usually less affected by chinooks than other parts of this area, and showed far less indications of early melting. They lie in a local wet belt, and above-normal rains in April and May probably account for the excess of actual runoff over forecast.

Okanagan Basin--A study of precipitation- and runoff-data indicated from the first that the fundamental relationship between snow-cover and runoff might very often be obscured by distorting factors.

Early spring and summer rains are usual and, falling on the still snow-covered areas, they no doubt have a marked effect in sustaining runoff. The area is semiarid, the summers are hot and dry, often with considerable wind, and if the hot weather comes early in place of the usual cooler weather and light rains it is quite evident that the evaporation-loss from the snow-cover may be excessive.

Correction for spring field-moisture-deficiency is now made (see paper by the writer, Trans. Amer. Geophys. Union, pp. 121-124, 1939), and when applied to two years of snow-survey data and past precipitation-records of snowfall it vastly improved their relationship to runoff. This factor appears to be an important one in this basin.

Unfortunately the available precipitation-records go back only 14, 11, and 10 years, respectively, at three stations, and during these periods of record there were no years of very marked deficiency in spring precipitation till 1938.

The wide discrepancy between forecast and actual runoff both in 1938 and 1939 now appears to have been due to the combined effects of deficient spring precipitation and abnormally high temperatures accompanied by dry winds over a long period commencing about the middle of March. As the normal precipitation in inches during April, May, and June is not heavy, its lack alone could not have accounted for the great discrepancy. It is believed, therefore, that a large part of this loss was due to evaporation of the snow caused by the abnormally early and prolonged warm dry spell. The same conditions prevailed both in 1938 and 1939, but, although more marked in 1939, the greatest discrepancy occurred in 1938, which suggests the possibility of some additional distorting factor.

In light of this experience, a study is being undertaken to try to correlate any discrepancy between snow-cover and runoff with abnormal spring precipitation, maximum daily temperatures (probably on the basis of degree-days above optimum minimum, such as 50° F), and evaporation-pan records which are kept at Summerland above Okanagan Lake.

In case any members are interested, I enclose a map showing distribution of courses.

Water Rights Branch,
Department of Lands,
Victoria, British Columbia

IMPROVEMENT OF EQUIPMENT

SOME HANDY KINKS FOR FIELD-MEN

Philip S. Cowgill

In order to prevent snow from freezing to the sampling tubes it has, for many years, been customary to shellac the tubes. Apparently it has been general practice, at least in the Sierra Nevada region, to use only white shellac for this purpose.

I followed this practice until one season I was unable to obtain white shellac and was compelled to substitute orange. I found that it worked equally well and showed better on the tube, making it much easier to determine when a thorough job had been done. It has been our experience that, under certain weather-conditions, even a small spot that is not properly coated will cause plugging of the sampler.

The orange shellac gives a brassy appearance to the tube which shows up much better, making it easier to find a section which has been dropped and has rolled a couple of hundred yards down-hill.

Another advantage we have noticed is that when a tube is heavily coated on the outside the shellac settles in the graduations, making them stand out more clearly. Dr. Church has been experimenting with red coloring in the graduations, but with a heavy coating of orange shellac this seems hardly necessary.

In shellacking the tubes it has been customary to cover the slots with adhesive tape to prevent the shellac from running out. Lately I have been using Scotch drafting tape, such as is generally used in drafting room for sticking down drawings. It seems to serve the purpose as well as adhesive tape and is less expensive.

At this time I would like to suggest an improvement in the carrying cases furnished for the duralumin tubes. Quite often, especially on short trips, a knapsack is unnecessary or one man can carry all the extra equipment for the entire party, while the others carry the sampler rolls. In such a case we find it advantageous to attach an extra transverse strap to the roll and sling it on the back like a knapsack. The roll rides in a vertical position where it will not catch when going between close trees, as it may do if carried crosswise. It also balances evenly, which is not the case if it is slung over one shoulder by a single strap. If the roll has a tendency to rock back and forth across the back, another strap may be attached to the lower end and tied around the waist or attached to the belt.

One of the greatest discomforts I have experienced in sampling is from soaked mittens and wet hands. To prevent this I now use a pair of rubberized gloves which can be purchased at department stores at a cost of from 25 to 40 cents. They have a fleece lining, which prevents them from feeling too cold on the hands. One can often get a better grip on the sampler with such a glove than is possible with leather or woolen mittens or with bare hands. One of the great advantages is that when the sampling is completed the gloves are tucked away in the pack and regular ski mittens are resumed, dry and comfortable, for the return trip.

Sierra Pacific Power Company,
Reno, Nevada

DISCUSSION

Mr. Cowgill showed samples of tubes not treated, treated with white shellac, and treated with orange shellac.

SPENCER MUNSON--"When you are shellacking the inside of the tube, what do you use? A swab?"

MR. COWGILL--"Yes. A dipping arrangement would be very good but you would have to protect threads by a heavy coat of cup grease." In response to a question about using paraffin, Mr. Cowgill said that he had tried it but had a lot of trouble with it, so he went back to shellac. He said he was now working on a tank with an alcohol solution for removing shellac. It was suggested by someone from the floor that the tube be put in a bath of Oakite. This was answered by the statement that Oakite is ideal for steel samplers but destructive to aluminum alloys.

MR. PAGET--"Did you ever have any trouble having the adhesive tape destroy the shellac?"

MR. COWGILL--"I hadn't noticed that. I am always careful to protect tube and remove all particles of the gum that might stick to the tube."

MR. McLAUGHLIN remarked that the new ones were of anodized duralumin and that it was much harder to scratch than the old untreated duralumin.

MR. COWGILL again urged the use of a second strap on the packing cases, saying that they can be slung on the back easier that way. Furthermore, that the Government should furnish rolls with two straps.

MR. McLAUGHLIN asked him to write a letter to him to that effect.

DR. CHURCH--"Mr. Cowgill's 'kinks' represent an extension of the welfare suggestions made by Fred Paget to California Cooperative Snow-Surveyors (Trans. Amer. Geophys. Union, pp. 60-61, 1939). To these can be added non-sweat and therefore non-condensation snow goggles of French make, possessing both lightness and warmth. These have been reported by Wayne Poulsen, Ski Instructor, Reno, Nevada. The trade name is Emile Alis Goggles.

"As a substitute for tannic acid to ward off snow-burn, the editor again suggests the use of a flour or sugar sack as helmet. Cut the sack sufficiently short to reach only to the shoulder. Cut an oval opening in the sack in front of the eyes and place a willow or metal hoop at the bottom of the sack to assure ventilation. This ventilation is improved by the presence of a hat brim to hold the sack free from the face. The thinness and open-weave of the sack aid air-circulation, yet ward off the cold wind and snow. The resemblance to a Kuklux Klanner constitutes no peril in the solitudes."

FORMS FOR RECORDING AND REPORTING MEASUREMENTS

R. L. Parshall

The following forms, used for reports from the field and for office-records in connection with our cooperative snow-surveys, are being submitted for suggestions that may be helpful to those interested in this type of work.

These forms are self-explanatory and should need no special comment. The form entitled "Survey notes" is derived largely from Dean George D. Clyde of Utah State Agricultural College and others.

Form 1--Active snow-courses in Wyoming, New Mexico, and Arizona, spring 1940

No.	Name	Main drainage	Elevation	Forest
	WYOMING (39 active courses)			
3	Brooklyn Lake	North Platte River	10,200	Medicine Bow
7	Bottle Creek	North Platte River	8,200	Medicine Bow
8	Webber Spring	North Platte River	9,000	Medicine Bow
9	Old Battle	North Platte River	9,800	Medicine Bow
10	Rambler R. S.	Colorado	8,600	Medicine Bow
11	Fox Park	North Platte	9,200	Medicine Bow
13	Tensleep R. S.	Big Horn	8,300	Big Horn
14	Dome Lake	Big Horn	8,800	Big Horn
15	Shell Creek R. S.	Big Horn	7,700	Big Horn
16	Ranger Creek	Big Horn	8,800	Big Horn
17	Big Goose Creek R. S.	Tongue River	7,700	Big Horn
23	Dutch Joe R. S.	Green River	8,700	Wyoming
24	Lower Mulligan Park	Green River	8,900	Wyoming
25	Kendall R. S.	Green River	7,900	Wyoming

Form 1--Concluded

No.	Name	Main drainage	Elevation	Forest
	WYOMING--Concluded			
26	Loomis Park	Green River	8,500	Wyoming
27	Snyder Basin R. S.	Green River	8,040	Wyoming
28	Piney-La Barge	Green River	8,750	Wyoming
29	Grannier Meadows	Sweetwater	8,600	Washakie
30	Red Fork	Powder River	7,500	Not on Forest
31	Sour Dough	Powder River	8,500	Big Horn
32	Sylvan Pass	Shoshone	7,125	Yellowstone Nat. Park
33	Upper Hardpan Basin	Shoshone	9,500	Shoshone
34	Pole Mountain No. 2	South Platte	8,700	Medicine Bow
35	Libby Lodge No. 2	North Platte	8,700	Medicine Bow
36	Hair Pin Turn No. 2	North Platte	9,525	Medicine Bow
37	North French Creek	North Platte	10,200	Medicine Bow
38	N. Barrett Creek No. 2	North Platte	9,400	Medicine Bow
39	Ryan Park No. 2	North Platte	8,400	Medicine Bow
40	Lupine Creek	Yellowstone River	7,300	Yellowstone Nat. Park
41	Blacktail Deer Creek	Yellowstone River	7,500	Yellowstone Nat. Park
42	Beaver Dams	Yellowstone River	7,200	Yellowstone Nat. Park
43	Lodge Pole	Yellowstone River	8,200	Shoshone
44	East Rim Divide	Green River	7,950	Wyoming
45	Sawmill Glade	Big Horn	8,500	Washakie
46	Blue Ridge	Big Horn	9,500	Washakie
47	South Pass	Big Horn	9,050	Washakie
48	Wood River	Big Horn	8,000	Shoshone
49	Sheridan Creek R. S. No. 2	Big Horn	7,500	Washakie
50	Brooks Lake No. 3	Big Horn	9,200	Washakie
	NEW MEXICO (16 active stations)			
1	Red River	Rio Grande	9,500	Carson
2	Taos Canon	Rio Grande	9,000	Carson
4	Aspen Grove	Rio Grande	9,100	Carson
5	Lee Ranch	Rio Grande	9,050	Santa Fe
6	Canjilon	Rio Grande	9,500	Carson
7	Rio Nutrias	Rio Grande	7,900	Carson
8	Panchuela	Rio Grande	8,500	Santa Fe
9	Hematite Park	Canadian	9,500	Carson
10	Ocate Mesa	Canadian	9,200	Not on Forest
11	Frisco Divide	Gila-San Francisco	8,000	Apache
12	Tres Ritos	Rio Grande	9,000	Carson
13	Washington Pass	Colorado	8,600	Navajo Indian Reservation
14	State Line	Gila	8,000	Apache
15	Pay Role	Rio Grande	10,000	Carson
16	Jicarilla	Chama	8,500	Jicarilla Ind. Res.
17	Chama Divide	Chama	7,750	(Tierra Amarilla Grant)
	ARIZONA (7 active stations)			
2	Roof Butte	Colorado	8,500	Navajo Indian Res.
3	Nutrioso	Gila-Little Colorado	8,500	Apache
4	Beaver Head	Gila-Blue	8,000	Apache
5	Coronado Trail	Gila	8,000	Apache
6	McNary	Salt	7,200	White Mtn. Indian Res.
7	Forest Dale	Salt	6,800	White Mtn. Indian Res.
8	Trout Creek	Salt	6,400	White Mtn. Indian Res.

Form 2--Active snow-courses in Colorado, spring 1940

No.	Name	Main drainage	Elevation	Forest
	COLORADO (75 active stations)			
1	Cameron Pass	S. Platte and N. Platte	10,300	Roosevelt
2	Chambers Lake	South Platte	9,000	Roosevelt
3	Big South	South Platte	8,600	Roosevelt
4	W. Portal Greeley-Pou. Tunnel	North Platte	8,600	Roosevelt
5	E. Portal Moffat Tunnel	South Platte	9,400	Roosevelt

Form 2--Continued

No.	Name	Main drainage	Elevation	Forest
	COLORADO--Continued			
6	Dry Lake	Colorado	8,200	Routt
7	Park View	N. Platte and Colorado	9,200	Routt
8	Columbine Lodge	N. Platte and Colorado	9,300	Routt
9	Elk River	Colorado	8,700	Routt
10	Lynx Pass	Colorado	9,100	Routt
12	Phantom Valley	Colorado	9,300	Rocky Mtn. Nat. Park
14	Hoosier Pass	S. Platte and Colorado	11,400	Pike
15	Fairplay	South Platte	10,000	Pike
16	Berthoud Pass	Colorado	9,700	Arapaho
18	Crested Butte	Colorado	9,000	Gunnison
19	Tennessee Pass	Colorado and Arkansas	10,200	Cochetopa
21	Twin Lakes Tunnel	Arkansas	10,125	Cochetopa
22	Major Creek	Colorado	10,500	Cochetopa
23	Rico	Colorado	8,700	Montezuma
24	Telluride	Colorado	8,600	Montezuma
25	Lizard Head	Colorado	10,300	Montezuma
26	Wolf Creek Pass	Rio Grande	10,000	Rio Grande
27	Upper Rio Grande	Rio Grande	9,350	Rio Grande
29	Upper San Juan	Colorado	10,000	San Juan
30	Silverton Substation	Colorado	9,400	San Juan
31	Cascade	Colorado	8,850	San Juan
33	W. Portal Indep. Pass Tunnel	Colorado	10,200	Holy Cross
34	N. Lost Trail Creek	Colorado	9,200	Holy Cross
35	Burro Mountain	Colorado	9,000	White River
36	Rio Blanco	Colorado	8,500	White River
37	Middle Fork Camp Ground	Colorado	9,000	Arapaho
38	Sunshine Mountain	Colorado	10,200	Gunnison
41	Wild Basin	South Platte	10,000	Rocky Mtn. Nat. Park
42	Marshall Creek	Colorado and Arkansas	10,850	Cochetopa
43	Poncha Creek	Arkansas	10,500	Cochetopa
44	Fiddler Gulch	Colorado	11,000	Holy Cross
45	Nast	Colorado	8,700	Holy Cross
46	Park Cone	Colorado	9,700	Gunnison
47	Silver Lakes	Rio Grande	9,600	Rio Grande
49	River Springs	Rio Grande	9,300	Rio Grande
50	Deadman Hill	S. Platte and N. Platte	10,200	Roosevelt
51	Big Creek Lake	North Platte	9,000	Routt
53	Alexander Lake	Colorado	10,000	Grand Mesa
54	Maroon Lake	Colorado	9,325	Holy Cross
55	Snowshoe Mesa	Colorado	7,500	Gunnison
56	Mesa Lakes	Colorado	10,000	Grand Mesa
58	Ironton Park	Colorado	9,800	Uncompahgre
59	Lulu	Colorado	10,200	Rocky Mtn. Nat. Park
60	University Camp No. 2	South Platte	10,300	Roosevelt
61	Loveland Pass No. 2	South Platte	10,100	Arapaho
62	Willow Creek Pass	Colorado	9,500	Arapaho
64	N. Inlet Grand Lake	Colorado	9,000	Rocky Mtn. Nat. Park
65	Lake Irene	Colorado	10,600	Rocky Mtn. Nat. Park
66	Thunderbolt Peak	Colorado	9,500	Arapaho
67	Fall River	South Platte	10,600	Rocky Mtn. Nat. Park
68	Hour Glass Lake	South Platte	9,500	Roosevelt
69	Arrow	Colorado	9,900	Arapaho
70	Lapland	Colorado	9,300	Arapaho
71	Deadman Hill No. 2	S. Platte and N. Platte	10,200	Roosevelt
72	Whiskey Creek No. 2	Arkansas	10,300	(Maxwell Grant)
74	La Veta Pass No. 2	Rio Grande	9,300	(Sangre de Cristo Grant)
75	Ute Ridge	Rio Grande	9,700	Rio Grande
76	Summittville	Rio Grande	11,500	Rio Grande
77	Cumbres Pass No. 2	Rio Grande and Colorado	10,000	Rio Grande
78	Four Mile Park No. 2	Arkansas	9,700	Cochetopa
79	Fremont Pass No. 2	Colorado and Arkansas	11,400	Arapaho
80	Santa Maria	Rio Grande	9,700	Rio Grande

Form 2--Concluded

No.	Name	Main drainage	Elevation	Forest
	COLORADO--Concluded			
81	Blue Lakes No. 2	Arkansas	10,000	San Isabel
82	Culebra	Rio Grande	10,000	(Sangre de Cristo Grant)
83	Jefferson Creek No. 2	South Platte	10,100	Pike
84	Fort Garland	Rio Grande	8,200	(Sangre de Cristo Grant)
85	Trickle Divide	Colorado	10,000	Grand Mesa
86	Trickle	Colorado	9,700	Grand Mesa
87	Park Reservoir	Colorado	9,500	Grand Mesa
88	Roach	North Platte	9,800	Roosevelt

Form 3

FEDERAL AND STATE COOPERATIVE SNOW-SURVEYS
UNITED STATES DEPARTMENT OF AGRICULTURE
DIVISION OF IRRIGATION, SOIL CONSERVATION SERVICE

SNOW-COURSE-DATA SHEET

Date ______________

NAME OF COURSE: ______________________________ State No. ______________

LOCATION: Sec. ______ T. ______ R. __________ Elevation ______________

DRAINAGE: Main ______________________ Local ______________________

NEAREST PERMANENT INHABITANTS: ______________________ Distance __________

LOCATING PARTY: ____

DESCRIPTION OF COURSE:

Topography ____

____

____

Vegetal cover ____

Uniformity of snow-cover ______________________________________

Earth-mantle ______________________ Soil-depth est. __________

Total length of courses ________ Interval ________ No. of Sta. ________

SNOW-COURSE-MARKER SIGNS:

Kind ______________ Number ______________ Height ______________

CLEARING:

Nature ____

SHELTERS:

Present facilities ______________________________________

____

Location of new shelters ______________________________________

____

Type ______________________ Est. cost ______________

Materials and construction by ______________________________

SNOW-SAMPLING EQUIPMENT:

Length of snow-tube __________ Tube No. ________ Balance No. ________

Use on other courses ______________________________________

Furnished by ____

OTHER EQUIPMENT NEEDED: (Snow-shoes) __________ (Skis and poles) __________

Furnished by ______________________________ Cost ______________

SNOW-SURVEYS:

Dates of surveys ____

Responsible cooperating agency ______________________________

Address ____

Party making survey ______________________________________

Financed by ____

REPORTS:

Responsible field-agent ______________________________________

Original notes to be forwarded to Irrigation Investigations, Fort Collins, Colorado.

BENEFICIARIES AND OTHER INTERESTED PARTIES: ______________________________

____

REMARKS: (Photos, transportation, telephone, telegraph, unusual conditions, etc.)

____

Form 4

Fort Collins, Colorado
______________19__

EQUIPMENT NEEDED IN THE FIELD FOR IRRIGATION-WATER-SUPPLY FORECASTING (COOPERATIVE SNOW-SURVEY PROJECT)

Number of carrying cases for equipment (canvas type) ______________
Snow-shoes--size, description
   (To be furnished complete with bindings) ______________
Skis--size, description
   (To be furnished complete with bindings) ______________
Ski poles (State type and length) ______________
Field notebooks (white) ______________
Record pink pads, 50 sheets (Form 143) ______________
Notebook covers ______________
Sketch maps (name snow-course)
   Letter size (8x10) (blue-print) ______________
   Snow-survey notebook size (photostat copy) ______________
Employment cards
Shelter-cabin needed. (Name snow-course)
   Remarks:
Other equipment and supplies needed
Are weighing balances and snow-tubes in good condition? ______________
Comments:

____
Forest Supervisor

Fill in items and return promptly to: ______________________
R. L. Parshall, Fort Collins, Colorado National Forest

Form 5

FEDERAL-STATE COOPERATIVE SNOW-COVER SURVEYS (Federal, State, and Private Agencies)

SURVEY NOTES

Directions and suggestions for snow-cover sampling

(1) The usefulness of snow-cover surveying depends primarily on the care and honesty of the men actually doing the field-work.

(2) The work of the snow-cover surveyor is often laborious, especially in stormy weather, and men willing to undertake such work can usually be depended upon to do their best and record the results faithfully.

Directions for using the snow-sampler

A--Care of sampler

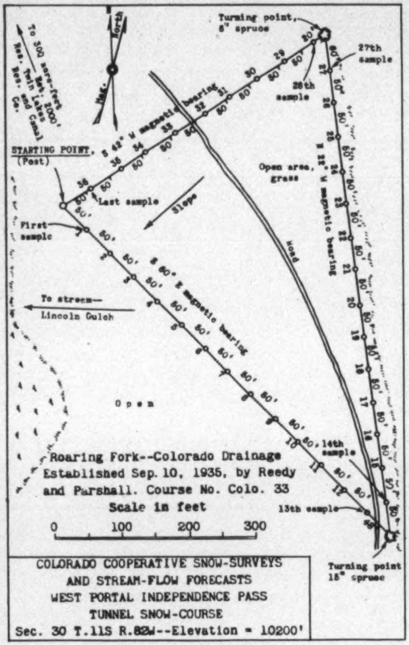
(1) In transporting sampler, extreme care should be used to guard it against injury; it can be easily dented.

(2) When sampling on steep slopes do not cling to the sampler to avoid sliding down-hill; the tube is easily bent.

(3) Keep the sampler covered inside and out with a thin coating of shellac or paraffin. The inside coating can be applied by pulling through a swab soaked or wet with shellac. This coating not only prevents corrosion but tends to keep moist snow from adhering to the tube.

(4) Since ice and rock sound and feel alike when struck by the sampler, be careful to determine what the substance is; ice will not blunt the cutter, rocks will.

(5) Keep the cutter sharp and the orifice true to its original diameter (1-1/2 inches inside in case the Mount Rose Steel Tube is used, and 1.485 in case the improved Utah duralumin


To 300 acre-feet Res. Twin Lakes Res. and Canal Co. Est. 2000'
North
Mag.
Turning point, 8" spruce
27th sample
28th sample
STARTING POINT, (Post)
S 42° W magnetic bearing
Last sample
First sample
Open area, grass
N 22° W magnetic bearing
Slope
Road
S 60° E magnetic bearing
To stream--Lincoln Gulch
Open
14th sample
13th sample
Turning point 15" spruce
Roaring Fork--Colorado Drainage
Established Sep. 10, 1935, by Reedy and Parshall. Course No. Colo. 33
Scale in feet
0 100 200 300
COLORADO COOPERATIVE SNOW-SURVEYS AND STREAM-FLOW FORECASTS
WEST PORTAL INDEPENDENCE PASS TUNNEL SNOW-COURSE
Sec. 30 T.11S R.82W--Elevation = 10200'

tube is used). To replace a damaged or worn cutter, heat the tube but only sufficiently to melt the solder that holds the old cutter and then sweat the new cutter into place.

B--Measuring for samples

Always start measurements for sampling from the initial point as shown by the sketch-map of the course and follow the spacing for samples as indicated by the circles. Note any irregular spacing between samples. Care should be used to space by tape measurements, so that the samples taken different years on the same course will be at the same spots.

(1) Plunging the tube should be avoided. In driving, a steady downthrust is preferable to twisting, because with the latter a small amount of snow enters the slots. However, a minimum amount of twisting aids in the driving and also facilitates the quick cutting of the thinner crusts. Plunging should be entirely unnecessary. In case the sampler sticks or freezes down, a light twist will usually release it.

(2) The presence of temperature below 32° F in the snow, while the temperature of the air is above freezing, often causes the snow to adhere firmly to the orifice of the cutter after a depth of from 10 to 12 feet has been reached. This difficulty can be met in three ways:

(a) Withdraw the sampler when cutter becomes clogged and clean cutter and tube thoroughly. Push the tube rapidly through the snow without stopping until bottom is reached but do not plunge tube. Repeat until a complete core is obtained. A complete core is one whose length is not less than 90 per cent of the depth of the snow.

(b) In case sampling is being done in the forest, keep the sampler in the shade as much as possible to keep it cold.

(c) The best method of all is to sample when the temperature of the air is at or below freezing, or late in the season when the temperature of the deep snow has risen to 32° F. At these times sampling is easy and rapid.

In some cases, where not too far from a night's lodging, time can be saved by taking the samples in the morning or evening instead of during the warm part of the day.

C--Weighing the sample

Before taking the sample, place the empty sampler-tube in the cradle hanging from the scales. Record the weight empty in proper column in field-book. When the sample has been taken, place the sampler in the cradle and record the weight of tube and core. The difference between these measurements equals the water-content of the snow-core. The weight of the tube empty should be checked at frequent intervals.

If dirt is picked up by the cutter it should be cleaned out with knife before weighing the sample, and proper deduction made before recording length of core or depth of snow.

D--Recording

The snow-survey notebooks are made up of perforated waterproof white sheets and are intended only for recording the original field-notes. The pink pads, letterhead size, are to be used to make copies from the white field-sheets as soon as possible after each survey. Instructions regarding the disposition of the original field-notes and pink copy sheets will be issued for each snow-course and addressed envelopes provided for mailing the records as requested.

Appropriate covers are to be provided for protection of field-notes. Sketch-maps showing points of observation are pasted to the inside of the covers.

Use pencil only for recording field-measurements. Fill in complete description of course, party, date, and other pertinent information. Record on field-notes the identification number of the sampling tube and weighing balance.

If the depth of core is very much less than the depth of snow, the reason should be determined and noted under "Remarks." In case of doubt regarding the core, determine the density (water-content divided by depth gives density) and compare with that of other adjacent measurements about which there is no doubt. "Remarks" should include special items as to the character of snow, nature and condition of soil reached by the cutter, whether wet, dry, frozen, and whether other surfaces or obstructions are encountered.

Any extended remarks as to weather conditions at the time of survey or shortly before the survey, unusual difficulties encountered, etc., may be placed on the back of the sheet, as one side only is to be used in recording the snow-measurements.

Fort Collins, Colorado,
January 10, 1940

Form 6

MEMORANDUM CONCERNING FEDERAL AND STATE COOPERATIVE SNOW-SURVEYS, SEASON 1940

It is very important that the snow-tube equipment be thoroughly inspected and, if possible, tried out before the observer goes into the field to take the measurements on the course. Give special attention to the balance to see that it is clean and in good working order. Read carefully the instructions on the first pages of the field-record book. If shellac is not available for treating the tube, a common paraffin candle, melted, may be used to swab the interior of the tube to reduce the resistance of the core in moving upward as the tube is thrust into the snow. It is necessary to warm the tube to get an even distribution of paraffin. After treatment with either paraffin or shellac, the threads of the snow-tube must be thoroughly cleaned. A small tin of grease is provided for use on the threads of the sampling tubes to prevent sticking.

In computing the results of the snow-survey the averages are to be determined as follows:

Add the snow-depths for the entire snow-course, including all lines, and divide by the total number of stations. The same method should be used for determining the average water-content. Where zero-depths of snow occur at the stations, these are to be included in computing the average.

It is requested that the average depth of snow in inches and the water-content in inches be wired to Fort Collins immediately after the survey has been made. The enclosed specimen copy is a form for the telegram, which should be sent as a Government message at the cheapest rate, collect. At the present time the Postal Telegraph Company does not maintain an office at Fort Collins. However, if it is found more convenient to use this service, the message can be relayed to Fort Collins from Greeley.

Forest supervisors are authorized to direct the rangers to engage the services of assistants, and horses, if necessary, to aid in making the surveys. The manner of preparing and submitting bills covering these services is to be followed as here outlined.

The bill should show: (a) Name and address of the employee; (b) name of snow-courses; (c) date of service; (d) days or hours employed and rate of pay; (e) services performed, such as assistance to ranger and horse hire; (f) signature of employee; (g) signature of ranger in charge. Send all bills to Fort Collins.

For Colorado, other than for the snow-courses covered by the Bureau of Reclamation, the account relative to the matter of paying the assistants is to be handled as outlined by special instructions to the supervisors. The rate of pay should be $5.00 per day, and for one-half day or less the time should be submitted at 50 cents per hour. Where horses are required on the work, the rate of pay is to be $1.50 per day per horse.

For the Colorado River courses where payment of services is to be made by the Bureau of Reclamation the special instructions attached are to be followed.

For Wyoming, the rate of pay should be $5.00 per day and for one-half day or less the time should be submitted at 50 cents per hour. Where horses are required on the work the rate of pay is to be $1.50 per day per horse. A single copy of bill approved by the ranger will be sufficient.

For New Mexico and Arizona, payment is to be at the prevailing local rate per day or at the equivalent rate per hour for fractional days. The bills for assistance and other expenses are to be submitted in duplicate on the United States Forest Service forms or some other suitable statement rendered in duplicate.

Fort Collins, Colorado,
January 10, 1940

Form 7

GENERAL INSTRUCTIONS

FEDERAL AND STATE COOPERATIVE SNOW-SURVEYS CONDUCTED UNDER THE DIRECTION
OF THE DIVISION OF IRRIGATION, SOIL CONSERVATION SERVICE,
U. S. DEPARTMENT OF AGRICULTURE, FORT COLLINS, COLORADO

General instructions concerning cooperative snow-course surveys
for the season________________________
Cooperating agency________________________
Supervisor________________________
Address________________________

Snow-courses assigned

Name	Expense charged to	Date of observations[a]			
		Feb. 1	Mar. 1	Apr. 1	May 1
No.					
No.					
No.					
No.					
No.					
No.					
No.					
No.					

[a] Observations to be taken as near these dates as it is practicable to do so.

Expenses for assistants to rangers and horse hire are to be chargeable as indicated above.

Form 8

CHECK SHEET FOR EQUIPMENT

COLORADO AGRICULTURAL EXPERIMENT STATION
Irrigation Investigations

Federal-State Cooperative Snow-Surveys

Fort Collins, Colo.
____

Memorandum to Forest Supervisor__________________
__________________National Forest

A check is being made as to the location of snow-survey equipment. Our records show the following has been issued to you and in use on your forest. I would be grateful if you will verify the notations below making such corrections as are necessary and return this list to me.

Tube No.	Extra sec.	Issued	Snow-course
Snow-shoes	Skis		
Canvas carrying-case			

Very truly yours,

R. L. Parshall,
Senior Irrigation Engineer
Soil Conservation Service

Form 9

MEMORANDUM TO SUPERVISORS CONCERNING RECORDS OF FEDERAL AND STATE COOPERATIVE SNOW-SURVEYS

Facilities have now been provided for filing in our fire-proof vault at Fort Collins the original snow-course-survey records (notebook white sheets) and it is therefore desired that these notes be kept on file at this office.

The pink-pad-record forms are for making duplicate copies of the original field-notes. These copies are to be kept on file at either or both the supervisor's or ranger's headquarters. After the transcriptions have been made the original notes are to be forwarded to Fort Collins in the addressed envelopes provided for this purpose. This duplication of record is intended to serve two purposes: First, that these data may be readily available at the offices of the supervisor and ranger for reference, and, second, in the event the original notes are either lost or destroyed the record in the field will then serve as a means of recovering these data.

A simple note in the original record showing the number of the sampling tube and number of the weighing balance will be appreciated as this information is useful in keeping our files up to date and may also prove valuable in the better interpretation of the results of the survey.

Fort Collins, Colorado,
January 25, 1938

Form 10

EQUIPMENT AND COST RECORD

State____________

Course____________________ Established________________

Drainage____________________ U. S. Forest________________

EQUIPMENT

Date____________

Snow-tube, length________, No.________, Scale________, No.________, Carrying case__________

Skis____________, Snow-shoes____________, Driving wrench_________, Spanner-wrenches________

COST RECORD

Date	Assistants	Subsistence	Mileage	Horse hire	Telephone, telegraph	Misc.	Total operation	Equipment		
								Date	Item	Cost

Form 11

REQUEST FOR REPORTS

1. The Law

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
Division of Irrigation

Fort Collins, Colorado
December 29, 1939

IMPORTANT NOTICE!

Under Section 6 of the Act making appropriations for the Treasury and Post-Office Departments for 1940 (Public No. 65 - 76th Congress) Federal Government Agencies may not send through the mail free of postage any "report, periodical, bulletin, pamphlet, list, or other article or document" unless this service has been requested (with certain formal exceptions).

The Irrigation Division of the Soil Conservation Service, in cooperation with the Colorado Agricultural Experiment Station, is planning to continue the issuing of monthly snow-survey and irrigation-water-supply bulletins covering the Rio Grande, Colorado, and Missouri-Arkansas drainages. In addition, bi-weekly reports of snow-conditions on the courses in Arizona will be issued this year. Please indicate on the enclosed card which reports you desire, stating the number of copies you need.

In order that you may receive our reports, it will be necessary, in accordance with the new Postal Regulations cited above, to have from you a formal request. An early reply will be appreciated.

Yours very truly,

R. L. Parshall
Senior Irrigation Engineer

Form 12

2. Application

Division of Irrigation
Soil Conservation Service
Colorado Agri. Expt. Station
Fort Collins, Colorado

Date__________

Gentlemen:

I desire to receive until further notice the monthly snow-survey and irrigation-water-supply reports as indicated.

	No. copies requested
Rio Grande Drainage.............	_____
Colorado Drainage..............	_____
Missouri-Arkansas Drainage......	_____
Special Arizona Bi-weekly Report	_____

______________________ ______________________________
______________________ ______________________________
Name Post-office address

REPORTS ON INVESTIGATIONS

SOIL-MOISTURE WITH REFERENCE TO RUNOFF

George D. Clyde
(Read by Carl Elges)

The following is merely a brief statement concerning the probable effect of soil-moisture conditions in Utah on water-supply forecasts.

In furtherance of our soil-moisture studies, we have continued to measure the precipitation in the Earth mantle just prior to the beginning of the snow-accumulation period. This year the measurements were made about the first of November. Unfortunately no precipitation occurred after that date on any of the watersheds until about December 20, with the result that the soil-moisture determinations showed a much higher moisture-percentage than was actually present at the time the snow began accumulating on the high watersheds.

General observations over the watersheds just preceding the snow in late December showed dry springs and water-holes, and where holes were dug the ground was found to be very dry to a depth of four feet, although no actual measurements are available. Conditions indicate that the Earth mantle is much drier at the present time than it was in the late fall of 1933 just preceding the 1934 drought. We are expecting, therefore, a considerable decrease in runoff per unit of accumulated water-content in the snow during this coming season.

Utah State Agricultural College,
Logan, Utah

MR. PAGET said that he had made a measurement on Donner Summit east of Sacramento, showing snow-cover of five feet, water-content 13 inches. That is more water-content than in January for the last two seasons.

A QUANTITATIVE FORECAST-SYSTEM OF RUNOFF BASED ON SNOW-SURVEYS AT THE MEAN ELEVATION OF THE SNOW-COVER IN THE MERRIMACK BASIN

John V. Salo
(Presented by J. E. Church)

Summary

The definite need of a simple "measuring stick" which would express the potential water-supply available in large snow-covers brought about the development of the "mean-elevation"

method of attack. Necessity demanded that the snow-survey data gathered from representative courses in the Merrimack River Drainage-Area be translated into useful information. The "mean-elevation" method interprets the significance of these snow-survey data. It provides a basis for determining potential water-supply existent in snow-covers of large areas by its interpretation of the data from the representative courses within those areas.

This need of a method of attack first became evident during the progress of the 1939 snow-surveys conducted in the headwaters of the Merrimack River. At that time, it appeared extremely appropriate to devise and utilize such a method because of the approach of the period of possible sudden and extreme runoff. Similar conditions in past years accompanied by heavy rainfall have brought disastrous results in this area.

Because of the fact that no previous snow-survey work or water-content analyses had been attempted in the Merrimack Area, no records were available for purposes of comparison. The snow-survey program carried on by the Public Service Company of New Hampshire was only first started in 1938 with the cooperation of the Weather Bureau, and then continued in 1939. The data obtained from this limited experience, particularly the surveys in 1939, serve as the basis for this report.

Upon the analysis of these data, the "mean-elevation" method of attack was formulated. Briefly, the calculations made by utilizing this method follow two general principles. First, it has been possible to construct a curve for each complete survey, which illustrates the general relation between water-content and elevation for the entire area as a unit. Second, in order to properly weight the data obtained from representative snow-courses in a given individual area, which is a part of the whole unit, we have tried to determine the water-content at the average or "mean-elevation" of that component area. This was accomplished by projecting this "mean-elevation" onto the "water-content-elevation" curve which was constructed in step one. These two principles are outlined in more detail in the body of this report.

By the use of this "mean-elevation" method, it has been possible to make complete calculations for each of the 1939 snow-surveys. This trend has been tabulated in detail in the original report. It will serve as a basis for future comparison and also will be used as a source for future analysis of runoff in an endeavor to determine the correlation between snow-cover and runoff.

The body of this report will illustrate the work carried out up to this time.

Method of survey--An explanation should be made of the frequency of surveys that we carry out, which is perhaps different from those conducted in the West. Our first complete survey is made in the middle of January and successive surveys are made at intervals of approximately two weeks. These surveys are continued through the runoff-period. This runoff usually is very noticeable by at least the middle of April, and we are able to follow its progress until the snow-cover is practically depleted.

Because of the changeability of New England weather, it is reasonable to expect a partial runoff early in the spring season, followed by additional increases in snow-cover. In some instances an expected partial runoff has turned into steady and rapid runoff because of changing weather-conditions. As a matter of record, the Merrimack Basin has experienced its severest flood-stages during spring runoff when heavy rainfall has been superimposed upon the snow-melt.

For reasons of this nature, it seems advisable to keep a check on our snow-cover until we feel certain that the steady runoff-period has safely begun.

The total drainage-area of the Merrimack River above Manchester represents 3059 square miles. The sub-areas in which the snow-survey field-work of 1939 was carried out are the two principal northern basins: The Pemigewasset River Area above Bristol and the Lake Winnepesaukee Area above Franklin. These two combined areas represent 1,335 square miles of drainage or slightly less than one-half of the basin above Manchester.

For 1940 ten new courses in an additional 766 square miles of drainage have been laid out. To survey these courses will require five days and approximately 600 miles travel by automobile and snow-shoe.

The detailed discussion of the method with inclusion of the analysis of snow-survey data through the present season of 1940 will be reserved for the meeting of the Snow-Survey Conference at Seattle in June.

Public Service Company of New Hampshire,
Manchester, New Hampshire

SOME FACTORS AFFECTING FROST-PENETRATION: A SUMMARY

H. B. Atkinson and Clyde E. Bay
(Presented by J. E. Church)

Starting with the winter of 1936-37, records have been kept on the penetration of frost under different farming practices, exposures, and cover-conditions. The data were collected on the Upper Mississippi Valley Soil Conservation Experiment Station farm, located at La Crosse, Wisconsin, which is about 43°5 north latitude. The soil-types, on which studies were made, are the Clinton Silt Loam which has a four- to six-foot loessial deposit over limestone and the Dubuque Silt Loam, which has a 12- to 24-inch loessial deposit over soil residual to limestone.

The measurements of frost-depth were obtained by the use of a King soil-tube and hammer. After measuring snow-depth the tube was driven into the soil-profile, a few inches at a time. The core-samples were removed and examined for ice-crystals. The depth to which these crystals occurred was recorded as the frost-depth. Three measurements were usually taken at each station.

Some of the factors which have been found to affect frost-penetration are snow-depth, vegetative cover, atmospheric temperature, and exposure. Other factors which probably have an appreciable influence but have not yet been closely studied are initial soil-temperature, moisture-content of soil, soil-type, and snow-density.

Conclusions--(1) Frost-penetration is closely related to vegetative cover, that is, frost-depth is less under the heavier vegetative cover.

(2) The greater the depth of the snow-mantle, the less the depth of frost-penetration, other things being equal.

(3) The snow-mantle and frost disappear from the south exposures more rapidly than from the north exposures.

(4) A heavy rain occurring when the surface three or four inches of the soil is thawed and in a saturated state would result in the erosion of a large portion of this unfrozen layer in fall-plowed areas.

(5) Thawing takes place from the bottom of the frozen layer as well as from above.

Since the above conclusions were reached, additional data have been secured on the effect of the depth of snow-cover on frost-penetration and the effect of snow-cover on ground-temperatures. The latter study was made with a soil-thermograph. These will be included in the revised paper being prepared for the Seattle meeting.

Soil Conservation Experiment Station,
La Crosse, Wisconsin

DISCUSSION

DR. CHURCH commented that floods do not occur in seasons of very deep snow but rather in seasons of shallow snow, when it can more readily be melted by rain. Frost can occur under any vegetative cover, but warmth of the Earth may dispel it providing the snow-cover is sufficiently deep to check further entry of cold from the air and lies sufficiently long to permit the warmth of the Earth to act. Frost should be found in early spring where the snow is shallow or wind-swept, that is, in the lower parts of the basin where the ground is cultivated and forests are rare.

Birch or deciduous forests, because of their lack of foliage in winter, permit the snow to fall evenly and with little interception, and by their branches break up strong wind-currents and thus prevent drifting. However, they afford no shade against early melting. The conifers or evergreens, on the other hand, intercept some snow but shelter the remainder. Since both types of forest intercept and transpire water in the summer, the intermittent summer rains produce far less stream-flow relatively than the winter snow. Since the snow-cover passes into the soil as one continuous rain, it is probable that the winter precipitation, though constituting only one-third of the annual water-supply, provides two-thirds of the annual runoff. Thus in the East, where the snow is shallow, snow-surveying is essential in forecasting water-supplies. It is even more indispensable for determining flood-possibility.

WALTER J. PARSONS--"The problem of freezing ground under snow-cover is allied with freezing ice on rivers. After a winter thaw and the ice becomes bare, the depth of freezing may extend to three feet below the surface, but if there is snow-cover, the maximum depth will be only two feet."

PROGRESS-REPORT ON MOUNTAIN SNOWFALL-PROGRAM OF THE WEATHER BUREAU

Merrill Bernard and Ashton R. Codd

Reports have been rendered periodically telling of the progress made by the Weather Bureau in modernizing its procedures for measuring snowfall in the mountainous areas of the West. These reports have outlined the mountain snowfall-service from the early days when it was considered adequate to measure depth by a graduated scale, through the early phases in the development of snow-surveying, to the present-day station equipped with the shielded storage snow-gage. Historically, this service has paralleled the development of irrigated areas in the West, beginning before the time when the detailed knowledge of potential water-supply was considered essential to seasonal planning in irrigation-operations and before the significance of the water-content of snow was fully appreciated. Today there is a need for detailed and accurate information regarding the seasonal and areal distribution of snowfall as such affect irrigation and other activities depending upon water-supply.

Progress-reports made at previous meetings have told of the experimental work by J. C. Alter, now Official in Charge of the Weather Bureau at Salt Lake City. Mr. Alter's idea of a flexible shield grew out of the inability of a shielded snow-gage (Fig. 1) developed previously by Professor Marvin (then Chief of the Instrument Division of the Weather Bureau), to prevent the accumulation and ultimate dumping of snow into the gage during periods of little or no wind-movement.

Mr. Alter's earlier experimental work with the flexible shield is covered adequately in an article prepared by him and published in the Monthly Weather Review (July 1937). Of the 20 different types of shields investigated, the one shown in Figure 2 proved to be the most dependable up to that time. The apparent action of the shield is to close in against the container, thereby minimizing the updrafts which ordinarily disrupt the snow-catch. Mr. Alter also developed the idea of using a salt-brine to melt the snow as it fell into the container, and preventing loss by evaporation through the use of a thin film of oil. In operation, the amount of snow is determined by weighing the container and converting net weight to equivalent inches of water-depth. Obviously, one of the most important characteristics of this type of gage is the ability to operate it with minimum attendance without running the risk of losing the record at the station. Within the capacity of the container, the record is secured against loss in cases where the station cannot be visited at regular intervals or in the event it cannot be reached before the period of melting. The gage also measures precipitation in the form of rain as well as snow, producing a record for the entire year.

In order to give a real significance to the record, the stations are equipped with batteries of from three to five gages, the average of the battery becoming the average precipitation to be applied to that portion of the basin represented by the station.

Figure 3 shows one of the early installations in the Sangre de Christo Mountains in the headwaters of the Rio Grande in New Mexico. In this gage the shield consisted of half an ordinary lath snow-fence suspended around the container as shown, and supported above the expected depth of snow by a wooden tripod. Figure 4 shows a similar installation at Brighton, Utah, the support being constructed of steel. This Figure shows the method of weighing the container with a spring-balance.

The general design of the gage, including shields and support stand, was improved by Mr. Alter in 1938 (Fig. 5, et al) to provide an all-steel construction and adapt the gage to regions of much deeper snow. Certain changes were subsequently made by the manufacturer, the Julien P. Friez Company, notably the steelyard weighing device. Experiments are being continued at Salt Lake City, with a view to making still further refinements in the gage-design, if found desirable.

In the ultimate application of data gathered at mountain snowfall-stations to forecasting methods, it is believed essential to know the time of occurrence of snowfall, that is, the age of the increments building up the snow-mantle as such affects its density. Therefore, plans are being made to develop the best way of utilizing a recording rain-gage for this purpose. Some of the difficulties are obvious. The principal modification to be made in the available automatic rain-gage is to equip it with a clock mechanism capable of running at least 30 days without attendance. Also, the limited capacity of the container in the ordinary automatic rain-gage would require more frequent attendance than is often available at remote mountain stations. The need, too, for some means of measuring the intensity of rainfall during the critical melting period is

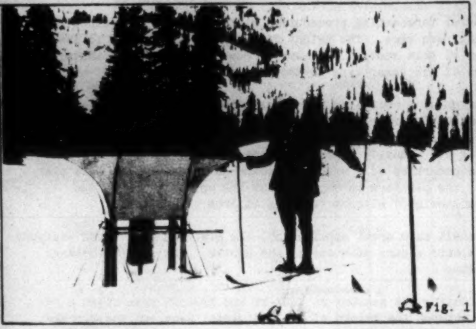


Fig. 1

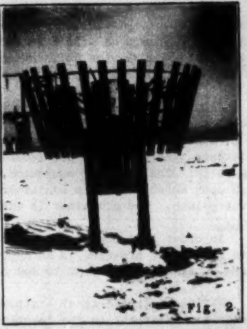


Fig. 2

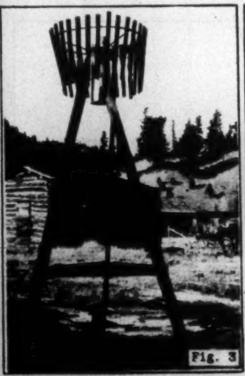


Fig. 3

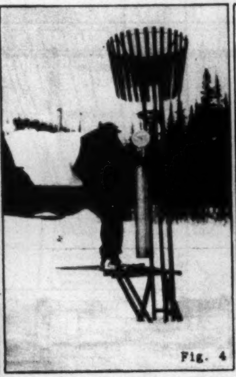


Fig. 4

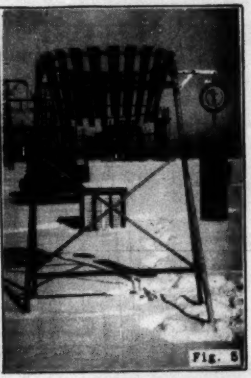


Fig. 5

Fig. 6

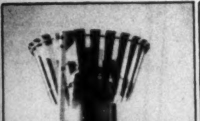


Fig. 7

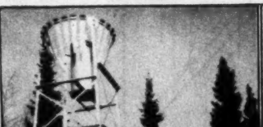


Fig. 8

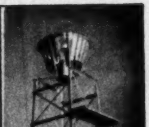


Fig. 9

believed to be important in a successful forecasting procedure. Figure 6 shows a shielded snow-gage support equipped with a recording rain-gage. The height of the tower is 15 feet to meet the expected cumulative depth of snow at this station. Figure 7 shows a similar gage installed at Leadville, Colorado, placed in one of the newer type 10-foot towers.

Figure 8 shows another installation of a recording rain-gage mounted on a 15-foot tower at the Weather Bureau station at Mesa Lakes, Colorado. Where greater depths of snow are expected, as at Cumbres Pass, Colorado, the gages are mounted on 20-foot towers, as shown in Figure 9. In this case, the gages are non-recording and manually operated by the weighing device shown in Figure 10. The weighing equipment is comprised of a steelyard which supports one end of a platform upon which rests the container. The platform is supported at the opposite end by two pivot-points. The container is thereby weighed without removing it from the platform.

In order that the measurements shall have areal application, the stations were first equipped with five gages arranged in an approximate square with one in the center. The spacing between gages varied from 200 feet to 900 feet.

Records gathered at 47 stations during the seasons of 1937-38 and 1938-39 have shown a remarkable consistency in the relation between the record of the individual gage and the average

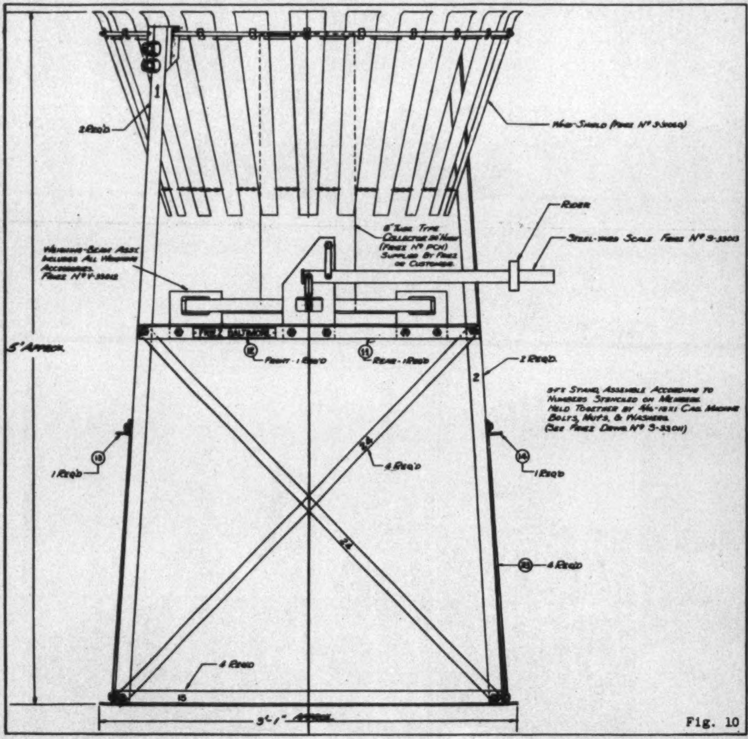
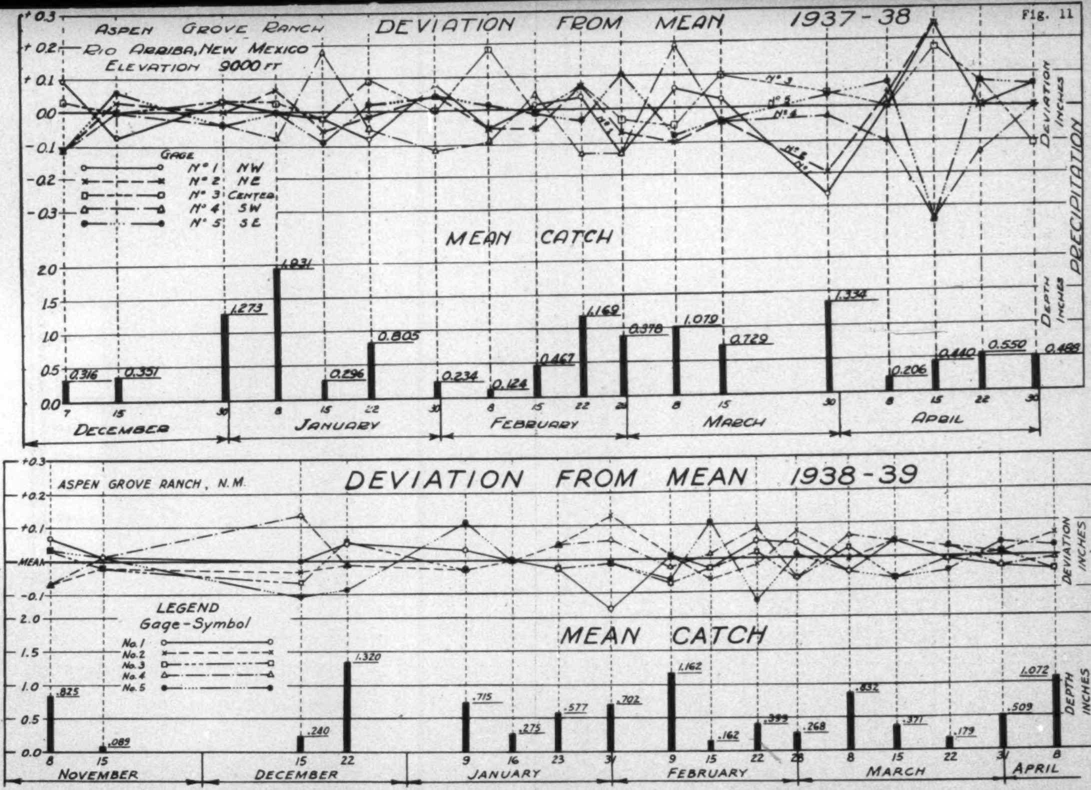

1
2 Req'd
Wind-Shield (Friez No 3-31050)
Rider
6" Tube Type Collector 24" High (Friez No PCH) Supplied By Friez or Customer.
Steel-yard Scale Friez No 3-33013
Weighing-Beam Assy. Includes All Weighing Accessories. Friez No V-33012
Friez Baltimore
5' Approx.
12
Front - 1 Req'd
11
Rear - 1 Req'd
2 Req'd
2
5 Ft Stand, Assemble According to Numbers Stenciled on Members. Held Together by 4¼-16x1 Car. Machine Bolts, Nuts, & Washers. (See Friez Drwg. No 3-33011)
13
1 Req'd
14
4 Req'd
14
1 Req'd
24
24
4 Req'd
4 Req'd
15
3'-1" Approx.

Fig. 10

Fig. 11


ASPEN GROVE RANCH
RIO ARRIBA, NEW MEXICO
ELEVATION 9000 FT
DEVIATION FROM MEAN 1937-38
GAGE
Nº 1 NW
Nº 2 NE
Nº 3 CENTER
Nº 4 SW
Nº 5 SE
MEAN CATCH
PRECIPITATION
DEVIATION INCHES
DEPTH INCHES
+0.3
+0.2
+0.1
0.0
-0.1
-0.2
-0.3
2.0
1.5
1.0
0.5
0.0
0.316
0.351
1.273
1.931
0.296
0.805
0.234
0.124
0.467
1.169
0.978
1.079
0.729
1.334
0.206
0.440
0.550
0.488
7
15
30
8
15
22
30
8
15
22
28
8
15
30
8
15
22
30
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
ASPEN GROVE RANCH, N.M.
DEVIATION FROM MEAN 1938-39
LEGEND
Gage-Symbol
No. 1
No. 2
No. 3
No. 4
No. 5
MEAN
+0.3
+0.2
+0.1
-0.1
2.0
1.5
1.0
0.5
0.0
.825
.089
.240
1.320
.715
.275
.577
.702
1.162
.162
.399
.268
.832
.371
.179
.509
1.072
8
15
15
22
9
16
23
31
9
15
22
28
8
15
22
31
8
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL

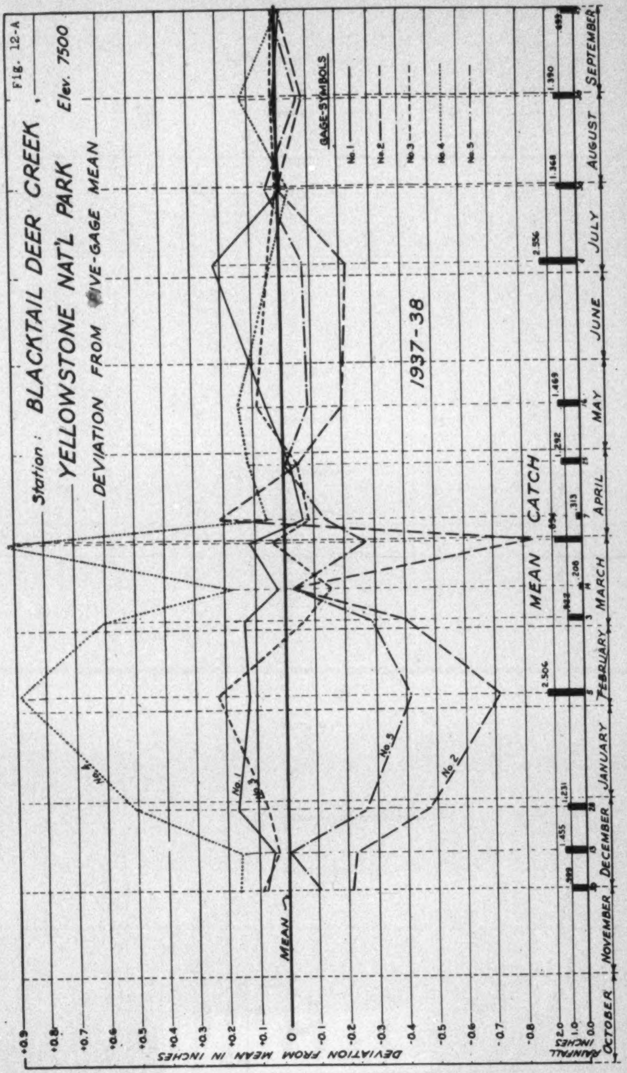


Fig. 12-A

Station: BLACKTAIL DEER CREEK, YELLOWSTONE NAT'L PARK Elev. 7500
DEVIATION FROM FIVE-GAGE MEAN
1937-38
MEAN CATCH
GAGE-SYMBOLS
No. 1
No. 2
No. 3
No. 4
No. 5
MEAN
DEVIATION FROM MEAN IN INCHES
+0.9
+0.8
+0.7
+0.6
+0.5
+0.4
+0.3
+0.2
+0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
RAINFALL INCHES
2.0
1.0
0.0
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
1.455
1.231
2.506
.206
.313
1.292
1.469
2.556
1.368
1.390

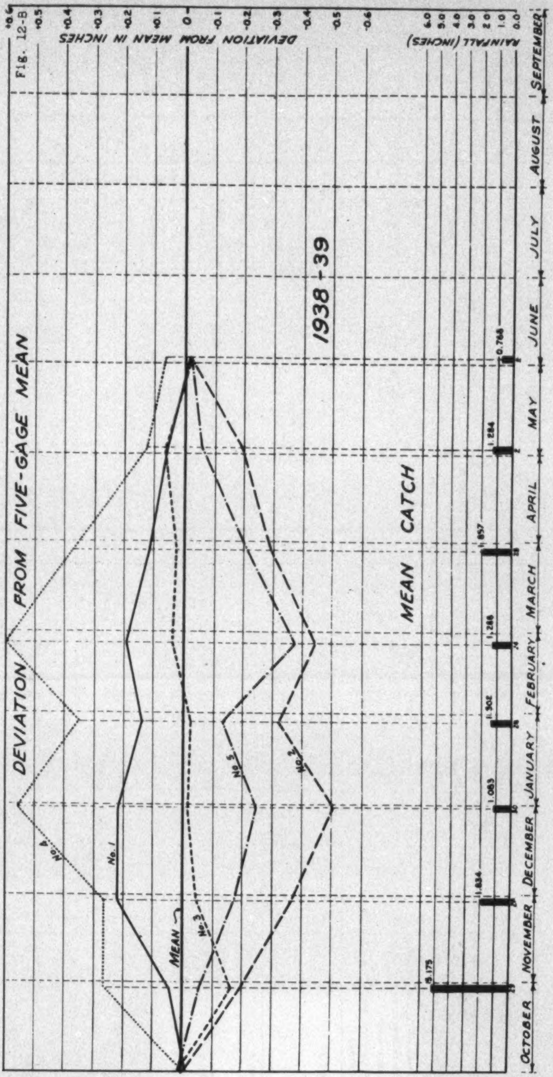


Fig. 12-B
DEVIATION FROM FIVE-GAGE MEAN
1938-39
MEAN CATCH
DEVIATION FROM MEAN IN INCHES
+0.6
+0.5
+0.4
+0.3
+0.2
+0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
RAINFALL (INCHES)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
No. 4
No. 1
Mean
No. 3
No. 5
No. 2
5.175
1.834
1.083
1.302
1.288
1.857
1.284
0.768
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER

for the battery. The record at Aspen Grove Ranch, shown in Figure 11, is typical of all but one in the total number of stations. In this record the average departure of any gage from the mean of the battery is less than 0.10 inch. It is to be noted that the consistency extends through the second year of operation. The evident improvement in the record is apparently accounted for in the greater experience on the part of the observer.

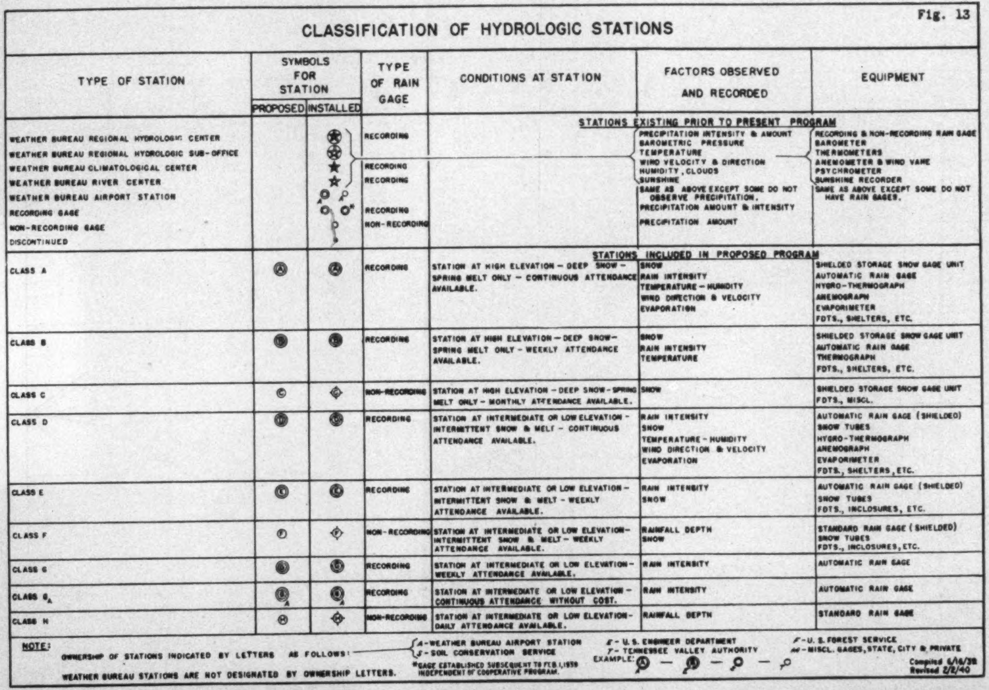


Fig. 13

CLASSIFICATION OF HYDROLOGIC STATIONS

TYPE OF STATION	SYMBOLS FOR STATION		TYPE OF RAIN GAGE	CONDITIONS AT STATION	FACTORS OBSERVED AND RECORDED	EQUIPMENT
	PROPOSED	INSTALLED				
					STATIONS EXISTING PRIOR TO PRESENT PROGRAM	
WEATHER BUREAU REGIONAL HYDROLOGIC CENTER		✪	RECORDING		PRECIPITATION INTENSITY & AMOUNT BAROMETRIC PRESSURE TEMPERATURE WIND VELOCITY & DIRECTION HUMIDITY, CLOUDS SUNSHINE	RECORDING & NON-RECORDING RAIN GAGE BAROMETER THERMOMETERS ANEMOMETER & WIND VANE PSYCHROMETER SUNSHINE RECORDER
WEATHER BUREAU REGIONAL HYDROLOGIC SUB-OFFICE		✪				
WEATHER BUREAU CLIMATOLOGICAL CENTER		★	RECORDING			
WEATHER BUREAU RIVER CENTER		☆	RECORDING			
WEATHER BUREAU AIRPORT STATION		○ ○			SAME AS ABOVE EXCEPT SOME DO NOT OBSERVE PRECIPITATION.	SAME AS ABOVE EXCEPT SOME DO NOT HAVE RAIN GAGES.
RECORDING GAGE		○ ○*	RECORDING		PRECIPITATION AMOUNT & INTENSITY	
NON-RECORDING GAGE		○	NON-RECORDING		PRECIPITATION AMOUNT	
DISCONTINUED		●				
				STATIONS INCLUDED IN PROPOSED PROGRAM		
CLASS A	Ⓐ	Ⓐ	RECORDING	STATION AT HIGH ELEVATION – DEEP SNOW – SPRING MELT ONLY – CONTINUOUS ATTENDANCE AVAILABLE.	SNOW RAIN INTENSITY TEMPERATURE – HUMIDITY WIND DIRECTION & VELOCITY EVAPORATION	SHIELDED STORAGE SNOW GAGE UNIT AUTOMATIC RAIN GAGE HYGRO-THERMOGRAPH ANEMOGRAPH EVAPORIMETER FDTS., SHELTERS, ETC.
CLASS B	Ⓑ	Ⓑ	RECORDING	STATION AT HIGH ELEVATION – DEEP SNOW – SPRING MELT ONLY – WEEKLY ATTENDANCE AVAILABLE.	SNOW RAIN INTENSITY TEMPERATURE	SHIELDED STORAGE SNOW GAGE UNIT AUTOMATIC RAIN GAGE THERMOGRAPH FDTS., SHELTERS, ETC.
CLASS C	Ⓒ	Ⓒ	NON-RECORDING	STATION AT HIGH ELEVATION – DEEP SNOW – SPRING MELT ONLY – MONTHLY ATTENDANCE AVAILABLE.	SNOW	SHIELDED STORAGE SNOW GAGE UNIT FDTS., MISCL.
CLASS D	Ⓓ	Ⓓ	RECORDING	STATION AT INTERMEDIATE OR LOW ELEVATION – INTERMITTENT SNOW & MELT – CONTINUOUS ATTENDANCE AVAILABLE.	RAIN INTENSITY SNOW TEMPERATURE – HUMIDITY WIND DIRECTION & VELOCITY EVAPORATION	AUTOMATIC RAIN GAGE (SHIELDED) SNOW TUBES HYGRO-THERMOGRAPH ANEMOGRAPH EVAPORIMETER FDTS., SHELTERS, ETC.
CLASS E	Ⓔ	Ⓔ	RECORDING	STATION AT INTERMEDIATE OR LOW ELEVATION – INTERMITTENT SNOW & MELT – WEEKLY ATTENDANCE AVAILABLE.	RAIN INTENSITY SNOW	AUTOMATIC RAIN GAGE (SHIELDED) SNOW TUBES FDTS., INCLOSURES, ETC.
CLASS F	Ⓕ	Ⓕ	NON-RECORDING	STATION AT INTERMEDIATE OR LOW ELEVATION – INTERMITTENT SNOW & MELT – WEEKLY ATTENDANCE AVAILABLE.	RAINFALL DEPTH SNOW	STANDARD RAIN GAGE (SHIELDED) SNOW TUBES FDTS., INCLOSURES, ETC.
CLASS G	Ⓖ	Ⓖ	RECORDING	STATION AT INTERMEDIATE OR LOW ELEVATION – WEEKLY ATTENDANCE AVAILABLE.	RAIN INTENSITY	AUTOMATIC RAIN GAGE
CLASS G_A	$Ⓖ_A$	$Ⓖ_A$	RECORDING	STATION AT INTERMEDIATE OR LOW ELEVATION – CONTINUOUS ATTENDANCE WITHOUT COST.	RAIN INTENSITY	AUTOMATIC RAIN GAGE
CLASS H	Ⓗ	Ⓗ	NON-RECORDING	STATION AT INTERMEDIATE OR LOW ELEVATION – DAILY ATTENDANCE AVAILABLE.	RAINFALL DEPTH	STANDARD RAIN GAGE

NOTE:

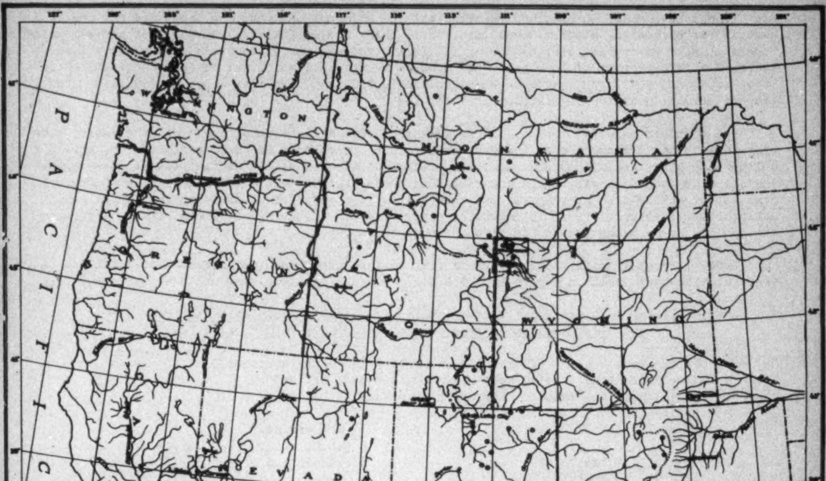
OWNERSHIP OF STATIONS INDICATED BY LETTERS AS FOLLOWS:
A – WEATHER BUREAU AIRPORT STATION
S – SOIL CONSERVATION SERVICE
E – U. S. ENGINEER DEPARTMENT
T – TENNESSEE VALLEY AUTHORITY
F – U. S. FOREST SERVICE
M – MISCL. GAGES, STATE, CITY & PRIVATE

EXAMPLE: Ⓐ – Ⓑ – ○ – ○

WEATHER BUREAU STATIONS ARE NOT DESIGNATED BY OWNERSHIP LETTERS.

*GAGE ESTABLISHED SUBSEQUENT TO FEB. 1, 1939 INDEPENDENT OF COOPERATIVE PROGRAM.

Compiled 6/16/39
Revised 2/2/40


PACIFIC OCEAN
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
COLORADO
ARIZONA
NEW MEXICO
COLORADO RIVER
Scale: 0 100 200 Miles
Mountain Snowfall Stations shown thus ●

U.S. DEPARTMENT OF AGRICULTURE
WEATHER BUREAU
RIVER AND FLOOD DIVISION

MAP OF WESTERN UNITED STATES
SHOWING LOCATION OF
MOUNTAIN SNOWFALL-STATIONS EQUIPPED WITH SHIELDED SNOW-GAGES

Fig. 14

It is believed the experience of the past two years has justified a reduction in the number of gages from five to three without sacrificing accuracy in determining the average depth. It is obvious, too, that as a record of a battery is continued the particular gage which most accurately registers the average can be identified, after which the other gages may be removed and used at other locations.

The exception in consistently small variations previously referred to (shown in Fig. 12) is the station located at Blacktail Deer Creek, Yellowstone Park. It is interesting to note that in addition to the similarity in the pattern of departures the individual gages occupy the same relative position in both years.

It has been shown on previous reports that the higher snow-producing areas are not adequately represented by Weather Bureau stations. There are approximately 1,300 stations measuring snowfall, with an average elevation of 4,174 feet. The network of mountain snowfall-stations equipped with batteries of snow-gages now numbers 92--four of which are below 5,000 feet, 46 between 5,000 and 8,000 feet, 37 between 8,000 and 10,000 feet, and five above 10,000 feet. The average elevation of the 92 stations is 7,643 feet.

The mountain snowfall-program of the Weather Bureau will be integrated into the Nation-wide hydrologic program conducted by the Weather Bureau and sponsored by the Departments of Agriculture and War. Under this program there will be at the end of the current fiscal year approximately 6,000 non-recording and 2,500 recording precipitation-stations. The purpose of the program is to provide data on rainfall and snowfall for all purposes involved in the control and utilization of water. Figure 13 shows the classification of the hydrologic stations based upon the factors to be measured and the circumstances to be met.

Table 1 shows a summary of the 92 stations equipped with shielded gages. The locations of these stations are shown in Figure 14. The Class A and B stations have not been fully equipped with all the necessary instruments as of this date; however, it is proposed to install the additional equipment and bring them up to standard in the near future. It is anticipated that the data gathered from these stations will aid materially in making hydrologic studies relating to the watersheds in which these stations are located.

Table 1--Statistical classification of mountain hydrologic stations established during the period October, 1937, to December, 1939

(1) Total number of mountain snowfall-stations established	92
(2) Stations located west of the Continental Divide	52
(3) Stations located east of the Continental Divide	40
(4) Stations classified by States:	
Arizona	12
Colorado	15
Idaho	2
Montana	9
Nevada	2
New Mexico	18
Utah	19
Washington	3
Wyoming	12
(5) Stations designated as Class A	8
(6) Stations designated as Class B	16
(7) Stations designated as Class C	68
(8) Stations equipped with batteries of three shielded snow-gages	46
(9) Stations equipped with batteries of five shielded snow-gages	32
(10) Total number of non-recording type shielded gages installed	295
(11) Total number of recording type shielded gages installed	24
(12) Stations below elevation 5,000	4
(13) Stations between elevation 5,000 to 8,000	46
(14) Stations between elevation 8,000 to 10,000	37
(15) Stations above elevation 10,000	5
(16) Average elevation of 92 stations	7643

U. S. Weather Bureau,
Washington, D. C.

DISCUSSION

L. STANDISH HALL--How much increase in accuracy do you get in using the metal shelter instead of laths?

ANSWER--There seems to be no marked difference. The action is equally good in the lath.

W. A. LANG--What is the capacity of the type of gage shown in the illustrations? Also how long does the recording gage operate without attention?

ANSWER--So far we have no recording gage; we only hope that we will find a gage such as perhaps might be developed by Leupold and Volpel. The past season the standard eight-inch container was used. The stations we have located so far are all accessible to attendants. The container or gage-bucket has been coated with Quigley's paint and charged with salt solution and oil to cover the top of the contents. There is the Fergusson recording rain- and snow-gage used particularly by the United States Soil Conservation Service. This will normally record for eight days or by special clock and gears for as long as 16 days. Set the recording pen at zero and start the clock. The only thing to do is to watch the bucket. The graph, by rising or falling, will record the precipitation or evaporation as it occurs.

J. E. CHURCH--In the case of precipitation-towers, care must be taken to avoid the usual slender cross-braces, for the snow may encase them and drag them down as it settles. Possibly the cross-braces could have a sharp upper edge capable of dividing the snow. At least rugged construction should be employed. Guy-lines must be discarded. At Donner Summit in the Sierra Nevada, where snow-depths of 10 to 20 feet normally occur, the pioneer precipitation-tower of the Weather Bureau was torn to pieces.

PROBLEMS OF THE DIVISION OF IRRIGATION IN FORECASTING WATER-SUPPLIES

Walter W. McLaughlin

The Chairman has announced that I am to discuss problems in forecasting irrigation water-supplies based upon snow-surveys. I will, however, discuss informally, and without a prepared presentation, the progress of our snow-survey and irrigation water-supply-forecasting program.

As you know, the Appropriation Act of 1935 carried an item in the allotment to the Bureau of Agricultural Engineering to coordinate snow-surveying, to extend, and, where necessary, to locate and maintain snow-survey courses. As a result of that appropriation, there was undertaken in the fall of 1935 a program to coordinate snow-surveying and standardize equipment and methods, and a plan for the exchange of data. That the information might be exchanged, it was essential that the same equipment be used and the same methods of surveying followed in each of the States.

As you know, the course method of snow-surveying was first promoted by the Nevada Agricultural Experiment Station under the direction of Dr. J. E. Church. Soon thereafter, the Utah Agricultural Experiment Station, under the direction of Professor Clyde, undertook a snow-survey and water-supply-forecasting program. California soon followed with its network of snow-courses and Oregon did something along this line.

In attempting to work out a unified program in the fall of 1935, the services of Dr. Church and Professor Clyde as collaborators were secured, and in cooperation with them the Division of Irrigation undertook the task assigned to it by Congress. I may report that at the present time the equipment has been fully standardized and the methods of snow-surveying have been unified. Numerous conferences have been held with those from the various Western States having to do with snow-survey work, and these have proven stimulating and most beneficial.

Snow-surveying, as we consider it, is a determination of the amount of water held in the watershed in natural storage as snow and ice at the beginning of the spring melt. So far, we have not attempted to more than casually estimate the amount of water held in the soil-mantle on the watersheds, but sufficient courses are established and samples taken over a watershed to give a rather accurate picture of the total water-content held in the snowpack.

The forecasting of irrigation water-supplies from snow-survey data is in most States undertaken by one or more committees. These consist usually of a representative of the Division of Irrigation, and associated with him a representative of the State Engineer's Office, usually the watermaster of the stream or streams, a representative of the Forest Service, and a representative of the water-users. In other words, the membership of the committee must be intimately familiar with the watershed for which a forecast is being made, since each watershed has its own peculiarities and forecasting problems.

In the spring of 1940 there will be measured throughout the Western States 753 snow-courses with a total of 14,295 sampling places. There will be employed approximately 2,000 snow-surveyors.

Many of our snow-survey courses are distant from highways and places of abode. It is necessary, therefore, to provide shelters readily accessible to these courses, where the snow-surveyors may find shelter at night or in time of a blizzard or other emergency. Where the courses are distant from human habitation, a snow-surveyor is always accompanied by at least one companion to be of such assistance as he can in the work, but more specifically to be helpful one to the other in case of the breaking of a snow-shoe or other accident.

We have available this winter some 339 shelters, only a part of which have been built specifically for the snow-survey work. In many cases cabins or other shelters belonging to mining companies, power-companies, lumber-interests, etc., have been made available to us. Some of these shelters are occupied throughout the winter and therefore it is unnecessary for us to stock these cabins in the fall. Where the shelters are not occupied during the winter, it is necessary for us to supply food, fuel, camp-utensils, etc. These are put in the cabins in the fall before the first heavy snow.

I am of the opinion that it would be impractical and tremendously expensive for any one Federal agency to undertake this job alone. It is essentially a cooperative undertaking and that is the basis upon which the Division of Irrigation has developed the program. In Oregon alone we have some 24 cooperators--Federal, State, local, etc.--and in Colorado 29 different cooperating agencies. Altogether, there are probably 45 or 50 different agencies cooperating. However, those bearing the brunt of the work of making the measurements in the field are rangers from the Forest Service and the National Park Service.

Our aim in forecasting the water-supply is to indicate the amount of water that will be available from the snow and from other sources during each two-week period of the summer and fall. It is the late-season water-supply usually that determines the acreage of the higher-priced crops, and it is for the most part the supply that determines the economics of the irrigation-farming.

There are many difficulties in determining the runoff of water from the snowpack. There are ten variables that may be divided into two classes. The first class, consisting essentially of six variables, may be termed physical characteristics. They are: (a) Geographical location; (b) watershed elevations; (c) watershed topography; (d) vegetative cover on the watershed; (e) soil-cover and subsurface formations on the watershed; (f) water in the soil-mantle beneath the snowpack at the time of spring melting.

In the second group, which are climatic, may be mentioned: (a) Elevation limits of the snow-cover; (b) winter precipitation; (c) runoff-period for precipitation; (d) climatic trend.

In the first group, five of the factors are constant, and the last one, which is moisture in the soil, is variable.

In the second group, the first three are variable, and with our present knowledge unpredictable far enough in advance to be of any service in forecasting the runoff.

I think it is unnecessary to discuss in detail these variables since the group attending this meeting is more or less familiar with these factors and with the difficulties incident to applying them in forecasting water-supplies. The Division of Irrigation, which was recently transferred to the Soil Conservation Service from the Bureau of Agricultural Engineering, has outlined research work to determine the effect of the storage of water in the soil-mantle on the runoff from the snowpack; also to determine the effect of frost in the soil-mantle on the runoff. This work has just been started but so far this year we have had little frost and little snow--two essential elements in our research program.

It occurred to me that if we could portray on a map for each State the snowpack on the watershed, in per cent of normal, and fit these State maps into a map showing the entire Western region, it would give us at a glance the probable water-supply for any part of the West.

In attempting to work out such a map, we ran into the difficulty of indicating the carry-over water-supply held in reservoirs. While we might have a snowpack indicating runoff of about 60 per cent of normal, there might be on the stream, and in numerous cases there has been, a storage carry-over of water that would give a full water-supply for the year. We then attempted to show on a map for each State the carry-over water-supply and the area of land which that supply would serve, and then to superimpose our water-supply from the snowpack.

We are making progress along this line but you can see the difficulties that we would meet each spring in working up such a map in sufficient time to be of service in determining the agricultural program for the season.

In the summer of 1937, I was asked by several agencies on the Pacific Coast why we could not furnish them information on snow that would be of value in determining conditions for winter sports. This would be a strictly service undertaking. After canvassing the situation we determined that we could furnish this service at a very slight additional cost since we already had our contacts in the field and it would be merely a matter of having that information sent to our Berkeley office or other headquarters quickly and accurately. Through our offices at Berkeley, Medford, Boise, Fort Collins, and Logan, we are supplying winter-sports information covering 64 winter-sports areas. This information is gathered Friday morning, telephoned or telegraphed to the headquarters office and made available over the radio that same evening and through the press and otherwise the following morning.

Here again, the cooperators who furnish much of the information are the Weather Bureau, the Forest Service, and the National Park Service. The information furnished is snow-depth and its condition for skiing and sleighing, the temperature-range for the day, road conditions, facilities for parking and accommodations at the inns, the forecast of weather-conditions over the week-end, and in some instances events of unusual interest that may occur at any winter-sports area over the week-end.

Our best information indicates that about two and one-half million people visit the winter-sports areas each season, and the number is rapidly increasing from year to year.

In the above I have attempted to review for you very briefly what we are doing in the field of water-supply forecasting and the service of broadcasting winter-sports information.

Division of Irrigation,
U. S. Soil Conservation Service,
Berkeley, California

DISCUSSION

MR. McLAUGHLIN added the following informal comments to his paper: Major Bowie, who is in charge of the activities of the United States Weather Bureau in California, suggested as early as the Reno meeting of the Snow-Survey Conference in 1933 broad cooperation with agencies interested in snow-surveying. We now have in the State of Oregon 24 such agencies and in California, 29. There are between 40 and 50 in these Western States with which we cooperate--Federal agencies, State agencies, local agencies, canal-companies, individuals, mining companies, lumber-companies, power-companies, etc. Of course, our greatest cooperators are the Forest Service and the National Park Service.

Our snow-survey work fits into the flood-control work especially in the Northwest. The occurrence of low-lying snow in Utah is rather a common thing in that State. You have there, according to Dean Clyde's letter, a potential flood-hazard. We predict water-supplies not as a total for the season but in two-week periods. After all what we are most vitally interested in is the late-season water, from the first of August on. We set up a committee. We feel this is necessary for the reason that it is impossible in our judgment for any individual to make the best forecast since he is not intimately familiar with all the watersheds in the State and all their trends. This committee is composed of men from different areas and is able to better arrive at a figure for these variables than any one individual can do. In practically all States we have a committee that makes the forecasts. In some States we have two or three committees. In Oregon we have three.

Three years ago we undertook furnishing reliable, accurate information for the use of the lovers of winter sports. This is the third season we are providing that service. We are giving this information this year for 64 areas throughout the West. We make a broadcast at nine every Friday evening. You will find that this information is in some of the gas stations in these Coast States. We broadcast over the National Broadcasting Company on the Coast, two stations in Idaho, two in Washington, four or five in Utah, and one in Colorado. We are able to cover the entire West. Here again we rely on our friends to furnish us practically all of the information. We get most of this from the Forest Service, the National Park Service, and the Weather Bureau, giving the report of weather-conditions over the week-end. Nice weather is forecast for this week-end with not too much snow.

N. E. EDLEFSEN--I was interested in the forecasts that were reported. They seem to be remarkably accurate. How do you explain that? In measuring the discharge from a stream with weirs you have to be pretty accurate in order to get it within ten per cent.

H. D. McGLASHAN--I think that in some cases we do better than ten per cent. In some cases we consider five per cent pretty good.

MR. McLAUGHLIN--I think we can all realize that in the snow-game we can reach five per cent.

DR. CHURCH--Ten per cent is all right; if you get one per cent, something must be wrong.

FRED H. PAGET--Mr. McLaughlin mentioned climatic and physical variables but did not mention spiritual.

A. L. SONDEREGGER--It never became so clear to me until this morning how important forecasting is. The Russian failure in Finland is said to be due to someone's error in forecasting.

SNOW ACTIVITIES--NATIONAL PARK SERVICE

R. D. Waterhouse

The areas under the jurisdiction of the National Park Service, lying as they do at the headwaters of the important streams as far as water-supply is concerned, are important from the viewpoint of snow-surveys.

In California, Sequoia and General Grant National Parks, Yosemite National Park, and Lassen Volcanic National Park all lie at the headwaters of streams which are important for irrigation and water-storage purposes. Crater Lake National Park in Oregon, while not as important from an irrigation standpoint, nevertheless assumes increased importance on account of winter sports. Mt. Rainier National Park in Washington and Olympic National Park in the same State have no particular importance from an irrigation standpoint but are of extreme importance for power- and winter-sports reasons.

Sequoia National Park makes monthly snow-surveys from January through April on the Round Meadow and the Panther Meadow snow-courses. These measurements are made by members of the ranger-force. In March of each year a survey of snow-conditions in the Hockett Meadow and Quinn Horse Camp areas is made. These areas are all in the neighborhood of eight to nine thousand feet in elevation and reflect conditions in the headwaters of the San Joaquin and Kern River watersheds.

Data collected are sent to the Division of Water Resources of the California State Department of Public Works at Sacramento. A weekly telegram is sent to the Weather Bureau at San Francisco each Monday afternoon from December through March giving snow-conditions at the Giant Forest. A weekly telegram is sent to W. W. McLaughlin, Chief of the Division of Irrigation at Berkeley, each Friday morning giving road conditions, winter-sports conditions, amount of snow, and general weather at Giant Forest. This material is incorporated in a radio broadcast over KGO each Friday. This information is sent in from December 22 through April.

Yosemite furnishes more snow-survey reports and general snow-sports information than any of the California Parks. Snow-surveys have been undertaken in Yosemite National Park for several years. The schedule for 1940 has been worked out on a cooperative basis as it has been for the past few years with the California Cooperative Snow-Surveys, Division of Water Resources, California State Department of Public Works. A total of nine snow-courses will be surveyed during the coming winter. Three of them--Snow Flat, Peregoy Meadow, and Gin Flat--will be surveyed each month. The making of surveys at Snow Flat will depend on whether or not weather-conditions are favorable and rangers are available. The above courses are at 7,000 to 7,500 feet in elevation. The balance of the courses--Lake Tenaya, Tuolumne Meadows, Fletcher Lake, Dana Meadows, Ostrander Lake, and Johnson Lake--will be surveyed only the latter part of March or first of April.

These courses give indication of snow-conditions at the 8,000- to 10,000-foot level in the headwaters of the Merced River and above the Hetch Hetchy Reservoir.

This information is sent to the Merced, Turlock, and Modesto Irrigation Districts, as well as to the State where it is incorporated with the general snow-condition report.

At the request of the Weather Bureau, San Francisco, starting December 11 and each Monday thereafter until the close of March, a wire is sent from the Yosemite Office to San Francisco showing depth of snow at various points.

Last year the same information was furnished the Weather Bureau at Fresno but to date no desire has been expressed by the Fresno Office for the same information this year.

Effective December 22 and on each Friday evening through April, the Division of Irrigation, Soil Conservation Service, United States Department of Agriculture, Berkeley, California, will have a 15-minute period beginning 9 p.m. over the National Broadcasting Company facilities to conduct a winter-sports radio program. Information will be furnished by this office regarding the conditions of roads, the character and depth of snow, and the weather. These programs were also conducted during the past two winters, when the agency was known as the Division of Irrigation, Bureau of Agricultural Engineering.

During the winter season, short-wave radio broadcasts are made by the park radio system from headquarters in Yosemite Valley to the outlying ranger-stations within the park, giving conditions of road and weather as well as information on the condition of winter-sports areas so that all the personnel may be informed in connection thereto. Such short-wave broadcasts may, of course, be picked up by any short-wave receiver and it has been the practice of radio station KYOS at Merced to pick up these park broadcasts locally and to disseminate the information over its local broadcasting facilities during the noon hour in the winter months.

In Lassen Volcanic National Park, a regular check of snow-conditions is made by the ranger-force but not to the extent that Yosemite does since the question of irrigation is not quite so important in the northern part of the State. Snow-surveying will, however, assume greater importance with the completion of the Shasta Dam, and, if the Park Service is able to do so, more exact and extended measurements will be made.

Regular radio reports are sent each Friday from 8:10 to 8:20 a.m. beginning on December 8, 1939, to R. A. Work of the Oregon Cooperative Snow-Surveys in Medford, Oregon. This information has to do with the condition of roads and reports on the winter-sports conditions. Lassen Volcanic National Park is a very popular skiing area and the Sulphur Works skiing terrain is one of the best in the State. The road is kept open from Red Bluff to the Sulphur Works checking station and is accessible throughout the winter with the possible exception of periods of severe storms.

To illustrate the extent to which Lassen is going in the line of winter sports, a ski-tow will be in operation in the Sulphur Works Area and the winter sports will continue until approximately May 15.

This year Manzanita Lake, which is on the north side of Lassen Peak, will be kept open except during periods of severe storm, and, since better accommodations for visitors are available in Manzanita Lake Area, it is expected that this part of the park will be much more popular than the Sulphur Works Area.

Crater Lake National Park has been cooperating with the Medford Branch of the Oregon Experiment Station with respect to the surveys in the park since 1929, at which time a snow-course was established at Annie Springs 1,000 feet in length.

Snow-measurements have been and are now taken every month during the winter to determine snow-depth, length of core, equivalent depth of water, and the density-percentage. These data are sent to the water master in Medford where they are combined into a composite report for the area.

Weekly telegraphic reports of snow-depth are submitted to the Weather Bureau at Portland during the winter months.

Daily and weekly weather- and snow-condition reports are carried by the Klamath Falls and Medford papers and the information is furnished also to the Chambers of Commerce, the Oregon Motor Association, the Oregon State Police, and radio stations, ski-clubs, and individuals who contemplate a trip to the park.

Crater Lake National Park is also becoming a very popular ski-area for residents both from the Klamath Falls Area and the Medford Area. A ski-lift is contemplated and is about to be constructed in this area and, as has been the case in the last few years, limited accommodations for winter visitors are provided at Park Headquarters.

Crater Lake Park keeps the roads open by the use of rotary snow-plows as far as headquarters on the west, and the State Highway Department has kept the road open from Klamath Falls to the park boundary on the east.

Mount Rainier National Park, due to the comparative non-importance of snow-conditions in relation to irrigation, water, and power, has not precisely measured snow-conditions as have Yosemite and Crater Lake. Since it lies on the west slope of the Cascades where only in very exceptional years there is insufficient water for all purposes, no necessity is felt for exact measurements. However, monthly surveys of the general conditions have been made by all district-rangers in the area and this information is compiled monthly and forwarded to the Weather Bureau. The National Reclamation Service surveys Nisqualley Glaciers periodically.

A daily short-wave radio schedule is maintained with the State Highway Department, Seattle, at 8:00 a.m. Temperatures, snow-depths, and general conditions of weather, road, and skiing for the Longmire and Paradise areas are reported on this schedule. All areas of the State report by radio to the Seattle Office of the State Highway Department, which relays the information to the Weatner Bureau. As soon as compiled in the weather-forecast for the State, this is sent again to the State Highway Department, which immediately relays back to all report-stations the forecast for the next 24 hours.

Olympic National Park has been handicapped by lack of personnel for making snow-surveys and the high country in this area is very seldom visited in the winter time. With the addition of more rangers as time goes on, snow-condition reports will be compiled in this area similar to those at Mount Rainier. Deer Park is becoming a popular ski-area.

The National Park Service has always been anxious to cooperate with all agencies desiring information which may be obtained in the national-park areas, and should any agency desire information which may be obtained by the ranger-force of the National Park Service, we will be very glad to furnish the requested information.

Region IV, National Park Service,
San Francisco, California

DISCUSSION

MR. WATERHOUSE represented also Regional Director Kittredge, who had been forced to the hospital for a serious operation. He commented further on the service of the National Parks as follows: All we do is collect data. We make no estimates. Mr. McLaughlin does this in his area and Mr. Work in Oregon. We use telephone, radio, and mail for getting our information to various agencies. Mt. Rainier sends to Seattle. Yosemite broadcasts over short wave. The use of the radio is becoming more important all the time. Fifteen out of 26 national-park areas have radio systems. Yosemite has nine watersheds all above 7,000 feet on which we have snow-surveys and some of these are up-river from the Hetch Hetchy. Our areas are pretty well manned. Snow-surveying is not anything very much out of the ordinary for us and we can do it easily. Sequoia is on two watersheds. Lassen sends its reports north, as does Crater Lake. Both of them are in fairly important areas as far as water is concerned. Water on the west side of the mountains does not interest us much because there is so much of it. The winter sports are probably our biggest trouble. Have ski-lifts going in at Lassen, Crater Lake, and Rainier with the possibility that Deer Park and Death Valley National Monument will have a ski-lift.

BUSINESS SESSION

ANNUAL REPORT

H. P. Boardman, Chairman, Executive Committee

A progress-report was made by your Chairman at the Los Angeles and Spokane regional meetings held in December 1938. Twenty-five attended the Los Angeles meeting and 33 the Spokane meeting, the latter being the first snow-survey conference in that north region. These were both interesting and profitable meetings, as can be seen by any not able to be present if they read the papers and discussions published last July as Part I of the Transactions of the American Geophysical Union, 1939.

As for several years past, Dr. Church and Carl Elges with their office assistants did most of the work of assembling and preparing these papers for publication and securing the necessary funds for their publication.

Since its organization, the annual reports of the Committee on Snow of the American Geophysical Union, of which Dr. Church is Chairman, have been published by the Union, but the cost of reprints which have been widely circulated has been borne by the Nevada Agricultural Experiment Station until this year. The Director of the Station concluded that this expense should no longer be borne by the Station since it furnishes much of the clerical service in connection with the preparation of these reports. In July 1939 it appeared that the funds contributed for the publication of the papers and discussions of the snow-survey regional conference would be ample, so your Chairman canvassed the members of the Executive Committee relative to using part of these funds for paying the cost of reprints of the above-mentioned report of the Committee on Snow of the American Geophysical Union. The vote was almost unanimous in approving such action, so that was the procedure followed.

Some of the reprints of the Transactions of the American Geophysical Union were mailed direct from Washington, while the Report of the Committee on Snow and part of the Transactions of the American Geophysical Union were mailed from Reno. With those mailed from Reno, Dr. Church enclosed a return postal card to check on the interest of the recipient. Here is his report on the results: Number of Reports and Transactions sent from Reno office, 845; cards returned, 429. Three hundred seventy-five desired both Report on Snow and Proceedings of Snow-Survey Conference, three desired Report on Snow only, two desired Proceedings of Snow-Survey Conference only, 32 desired neither (in most cases because they already had the complete Transactions of the American Geophysical Union), and 433 failed to answer. Twenty-four organizations purchased 1,445 copies of Transactions mainly for organizational distribution. Some members of the American Geophysical Union returned their reprints stating that they received the complete Transactions of the Union.

This year the reprints of the reports and papers of the two regional meetings also contain the papers on hydrology presented at these meetings and the pamphlet is larger than usual, thereby somewhat increasing the cost of mailing. Since it is necessary to pay the printer in Washington promptly, some advance of money is required before all is received from the contributors. Most of the contributors make their contributions in the shape of payments for specified numbers of copies of the reprints.

The following organizations contributed towards the cost of the Transactions of 1939: Nevada State Engineer; Metropolitan Water District of Los Angeles; Nevada Agricultural Experiment Station; Sierra Pacific Power Company; Southern California Edison Company; U. S. Bureau of Reclamation; State Water Commissioner of Arizona; Colorado River Water Conservation District (Western Colorado); Utah Agricultural Experiment Station; U. S. Forest Service; Los Angeles Flood Control District; U. S. Army Engineers; U. S. Geological Survey; California Department of Public Works (Water Resources Division); U. S. Weather Bureau; Montana Agricultural Experiment Station; Pacific Gas and Electric Company; U. S. Soil Conservation Service; Division of Irrigation, Soil Conservation Service; City of Los Angeles; Colorado Agricultural Experiment Station; Water Rights Branch, Department of Lands, British Columbia, Canada; National Park Service; Washington Water Power Company.

Summary of the receipts and expenditures

Receipts		
On hand June 30, 1939	$ 89.69	
Interest	0.55	
Collections on reprints to date	635.00	
Collections authorized but not yet received	50.00	
Still owing Dr. Church	52.66	$827.90
Expenditures		
Printing of 2,500 reprints of Western Interstate Snow-Survey Conference Reports	$540.00	
Handling charges in Washington including mailing	49.50	
Printing of 1,500 copies of Report of Committee on Snow, A.G.U.	140.00	
Stamps, postal cards, express, and mailing from Reno	98.40	$827.90

Notes: Other contributions expected should equal or exceed the balance due Dr. Church. [On April 30 additional purchases of $30.00 had been made.]

Our thanks are due to Dr. Church, who continues to be the moving spirit in expanding the usefulness of snow-surveying by contacting new people and organizations, both by correspondence and personally, who are already interested in snow or who are led to appreciate its importance by his enthusiasm.

The Auditing Committee [Spencer M. Munson and Ashton R. Codd] found the available time insufficient for a detailed audit of the financial statement but expressed approval of the accounts.

On motion by Chairman Boardman a vote of thanks was given Dr. Church for his work during the year.

Selection of By-Laws

After prolonged discussion of the conflicting principles of interstate and regional control, the following By-Laws were prepared for submission by letter-ballot to the membership.

BY-LAWS

WESTERN INTERSTATE SNOW-SURVEY CONFERENCE

(Tentative plan of January 12, 1940, subject to adoption by membership)

Activities--The formal activities of the Western Interstate Snow-Survey Conference shall consist of regional meetings for the presentation of reports and the discussion of problems connected with snow and ice.

Administration--The Administration of the Conference shall be vested in an Executive Committee and Chairman elected from its number, apportioned among the various regions of the Western States and adjoining provinces of Canada, including Alaska.

Zoning--For election and assembly purposes, the Western States shall be divided into four regions, corresponding to the divisions made by the Section of Hydrology of the American Geophysical Union, as follows:

(1) North Continental Divide Area, comprising Montana, Idaho, Eastern Washington and Oregon, Alberta, and the adjacent region to the East.
(2) South Continental Divide Area, comprising Colorado, Wyoming, Utah, New Mexico, and the adjacent region to the east.
(3) North Pacific Area, comprising Western Oregon and Washington (including the Cascades), British Columbia, and Alaska.
(4) South Pacific Area, comprising California, Nevada, and Arizona.

Number on Executive Committee--The total number of members on the Executive Committee shall not exceed 20 nor shall more than five be chosen from any one region. In the event of a region having a vacancy for any reason, the Chairman of the Executive Committee with the advice and consent of the incumbent Committee members for said region may, by appointment from within the region, fill the vacancy until the next election.

Nomination--Preceding each election, the members of the Executive Committee in each region shall name one member of the Conference from that region, who together with the others so chosen shall constitute a nominating committee to prepare a list of candidates for the four regions.

Election--The Chairman of the Executive Committee shall place the names of these nominees on a ballot to be sent to all members for final balloting, and the highest five from each region who shall receive the majority of the total votes shall be declared elected.

Who shall vote--Ballots shall be sent to each individual who has ever attended a snow-survey conference and also one additional ballot shall go to each organization interested in snow-surveys. An interested organization is defined as one who aids the snow-survey work either financially or with its field-personnel.

+Furthermore, because of the difficulty of attending conferences, ballots may be sent to those who make formal application to the Executive Committee to be considered as members of the Conference and whose application is approved.

+Moreover, the term organization shall be defined as an administrative unit, such as state, district, section center, national forest, national park, irrigation-project, power-company, agricultural or forest experiment station, etc.

Term of office--An election shall be held once every two years. The number of consecutive two-year terms that any member may serve is not limited.

Election of new Executive Committee Chairman and chairmen of regional groups--The incumbent Chairman shall write to each member of the new Committee asking that they advise him of their choice of one of their number to serve as new Chairman.

The incumbent Chairman, after he hears from a majority of the committeemen, shall advise them of the choice of the new Chairman as desired by the majority of the Committee, and at the same time shall turn his duties over to the new Chairman.

However, no incumbent Chairman shall succeed himself.

A local Chairman for each region may be chosen by each regional group in the Executive Committee. The incumbent Chairman of the entire Executive Committee shall conduct the election.

[Note--The above By-Laws have been approved by the South Pacific region at its Stanford meeting January 12, 1940, except the sections marked by a plus (+) sign. These sections have been included in an attempt to clarify the By-Laws as passed. The By-Laws will be considered as adopted if approved by the majority of the members of the Conference voting.]

University of Nevada,
Reno, Nevada

A balloting list of individuals and organizations was prepared in accordance with the intent of the By-Laws and the conduct of the election was entrusted to the Local Chairman, Fred H. Paget. The results have been tabulated and reported March 13, 1940, by Chairman Paget to Professor H. P. Boardman, Chairman, Executive Committee, Western Interstate Snow-Survey Conference, as follows:

"The election which you requested me to conduct for the ratification of the By-Laws for the Western Interstate Snow-Survey Conference has been completed.

"The ballots were counted on March 12. Three hundred ten ballots were sent out, and 110 were returned. There were no dissenting votes, although one came in blank and nine of the 109 yes votes came in without any signature on the envelope.

"I believe one could safely state without fear of successful contradiction that the By-Laws were adopted unanimously. Attached is a list of the members who participated in the voting.

"I presume that you, as Chairman, will notify the other 13 members of the Executive Committee of the outcome of the election. Each member of the Conference can be notified later when the new mimeographed mailing-lists are sent out to all of them."

TABULATION OF MEMBERS AND ORGANIZATIONS VOTING ON THE ADOPTION OF BY-LAWS FOR THE WESTERN INTERSTATE SNOW-SURVEY CONFERENCE

(Canvassed in Sacramento, March 12, 1940)

North Pacific Division

R. C. Farrow
R. A. Work

North Continental Divide Division

Lynn Crandall
W. A. Hill
Mark R. Kulp
W. E. Maughan
O. W. Monson
Thomas R. Newell
H. M. Wanser

South Continental Divide Division

Thomas C. Adams
Geo. D. Clyde
Ashton R. Codd
A. R. Croft
D. B. Freeman
F. C. Hart
Ivan E. Houk
Alan Laflin
H. L. Potts
A. B. Purton
Rex R. Reed
R. J. Tipton

Members living outside of specified areas

Merrill Bernard
G. A. Hathaway
R. E. Horton

Organizations purchasing reprints of Proceedings, Western Interstate Snow-Survey Conference, 1939

Metropolitan Water District of Los Angeles (Clayburn C. Elder)

Nevada Agricultural Experiment Station (S. B. Doten)

Colorado River Water Conservation District (F. C. Merriell)

South Pacific Coast Division

V. D. Armstrong
William W. Aultman
L. E. Blakely
Francis B. Blanchard
H. P. Boardman
G. B. Bodman
John F. Bonner
R. C. Briggs
J. B. Brown
Ernest I. Bulpitt
J. E. Church
Geo. P. Clements
F. R. Cline
Philip S. Cowgill
Cecil W. Creel
John W. Davis
George Deibert
S. B. Doten
Courtland Eaton
E. H. Fletcher
C. V. Givan
L. Standish Hall
Ralph C. Hall
S. T. Harding
George Hardman
Horace P. Hinckley
Walter L. Huber
James E. Jones
Oliver Kehrlein
Joseph Kittredge, Jr.
E. W. Kramer
William A. Lang
Finley B. Laverty
Charles H. Lee
George A. Lewis
G. F. McEwen
H. D. McGlashan
W. W. McLaughlin
Pete J. Maga
J. A. Magee
Ross W. Mathews
J. A. Millar
Samuel B. Morris
Preston P. Odekirk
Fred H. Paget
Wayne Paulsen
Thelo Perrott
J. E. Phillips
B. [illegible]. Ploeger
Albert Reed
G. V. Sager
A. J. Shaver
Leland S. Smith
Kenneth Smith
C. W. Sopp
F. J. Veihmeyer
R. D. Waterhouse
W. W. Weir
Thos. J. Welsh
Walter J. Wood
George M. Wills

Organizations voting

Inyo National Forest
(Fred Meckel)
Sequoia National Forest
(Trent L. Lombard)
Lassen National Forest
(Supt. A. G. Brenneis)
Turlock Irrigation District
(R. V. Meikle)
Southern California Edison Company
(J. F. Davenport)
Tulare Lake Basin Water Storage District
(Roy May)
Lassen National Park
(Eugene J. Barton)
Nevada Irrigation District
Yosemite National Park
(John R. Wosky)
Merced Irrigation District
(L. W. Hesse)
San Joaquin Power Division Pacific Gas and Electric Company
(R. D. Likely)
Pacific Gas and Electric Company
(Chas. Z. Yost)
California Division of Water Resources
(Harold Conkling)

Summary

Number of ballots sent out............	310
Total number of ballots returned.......	110
Number voting yes......................	109
Number voting no.......................	0
Number blank...........................	1

[Number received anonymously, 9]

EXECUTIVE COMMITTEE AND OFFICERS
WESTERN INTERSTATE SNOW-SURVEY CONFERENCE

Members

Region 1--North Continental Divide
Lynn Crandall
H. T. Gisborne
O. H. Hoover
James C. Marr
O. W. Monson

Region 2--South Continental Divide
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Region 3--North Pacific Coast
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Region 4--South Pacific Coast
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Joseph Kittredge, Jr.
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Officers

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MEMBERSHIP

Through the generous cooperation of the California Division of Water Resources, copies of the membership-list of the Conference are being sent to the individual members as preliminary to the election of a new Executive Committee. A complete set of mailing slugs has also been made.

The following form of application for membership has been prepared to facilitate the expansion of the membership particularly in the Pacific Northwest in preparation for the joint meeting of the North Pacific and North Continental Divide areas at Seattle, June 19-22, 1940.

APPLICATION FOR MEMBERSHIP
IN THE
WESTERN INTERESTATE SNOW-SURVEY CONFERENCE

To the Executive Committee:

In keeping with the By-Laws that, in addition to actual attendance at meetings, membership can also be attained through application and receipt of approval from the Executive Committee, I hereby make formal application for such membership in the Snow-Survey Conference.

Name_____________________
Official position____________
Address____________________

[Note: Such application entails no dues.]

LIST OF PERSONS ATTENDING WESTERN INTERSTATE SNOW-SURVEY CONFERENCE, STANFORD UNIVERSITY, JANUARY 12, 1940

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